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Technol.

# THE JOURNAL OF
# The Institution of Electrical Engineers

ORIGINALLY

## The Society of Telegraph Engineers

TEMPORARY OFFICES: 1, ALBEMARLE STREET, LONDON, W. 1.

FOUNDED 1871

"TO PROMOTE THE GENERAL ADVANCEMENT OF ELECTRICAL AND TELEGRAPHIC SCIENCE AND ITS APPLICATIONS."

EDITED BY P. F. ROWELL, SECRETARY.

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**VOL. 57, 1919.**

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*(Corrected 1st January, 1919.)*

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### Secretary.

P. F. ROWELL.

The Institution is not, as a body, responsible for the opinions expressed by individual authors or speakers.

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NOTE.—On account of the shortage of paper, the publication of the following papers, which have been read at meetings during the Session 1918–19, will be considered by the Council when conditions are again normal :—

G. L. ADDENBROOKE : Lectures on "Dielectrics in Electric Fields."

J. BIBBY : "Developments in Electric Iron and Steel Furnaces."

W. K. BOOTH : "The Booth-Hall Electric Furnace."

S. CHAPMAN : "Electrical Phenomena occurring at High Levels in the Atmosphere."

H. R. CONSTANTINE : "Co-ordination of Research in Works and Laboratories."

Lieut.-Col. A. G. T. CUSINS, R.E. : Lecture on "The Development of Army Wireless during the War."

Major A. C. FULLER : "The Fullerphone, and its Application to Military and Civil Telegraphy."

H. A. GREAVES : "Application of Electrical Energy to the Melting of Metals."

E. A. LAIDLAW and W. H. GRINSTED : "The Telephone Service of Large Cities, with special reference to London."

R. G. MERCER : "Electric Furnaces in the United Kingdom, 1918."

A. SAHLIN : "A New Type of Electric Furnace."

V. STOBIE : "Large Electric Steel Melting Furnaces."

Captain L. B. TURNER : "The Oscillatory Valve Relay : a Thermionic Trigger Device."

R. S. WHIPPLE : "Some Notes on the Electro-Cardiograph."

R. S. WHIPPLE : "Some Notes on Electrical Methods of Measuring Body Temperatures."

H. E. YERBURY : "The Effect of Air and Water on Materials used in Engineering Work."

## CORRIGENDA.

Vol. 57, p. 36, col. 2, last line : For "here" *read* "in Table 2."

Vol. 57, p. 261, col. 1, lines 23 and 24 : Delete "On the other hand . . . subject."

Vol. 57, p. 261, col. 1, line 27 : Before "The" *insert* "On the other hand so far as I have been able to obtain data on the subject."

Vol. 57, p. 407, par. 13 : After "Leeds Corporation" *add* "Woolwich Borough Council 31,425,000."

Vol. 57, p. 410, par. 30, line 6 : For "8,000 kw." *read* "10,500 kw."

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 9. DECEMBER 1918. INSTITUTION NOTES. [ISSUED WITH No. 277 OF THE JOURNAL.]

## Meetings for December 1918 and January 1919.

### ORDINARY MEETINGS OF THE INSTITUTION.

| *Date.* | *Author and Title of Paper* |
|---|---|
| 1918. | |
| 5 Dec. | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| 12 Dec. | Discussion on "Electric Welding." |
| 19 Dec. | P. HUNTER-BROWN: "Carbon Brushes: considered in relation to the design and operation of electrical machinery." |
| 1919. | |
| 9 Jan. | M. B. FIELD: "The Navigational (Magnetic) Compass as an Instrument of Precision" (Lecture). |
| 23 Jan. | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |

### MEETINGS OF TERRITORIAL CENTRES.

| *Date.* | *Place of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 1918. | | |
| 9 Dec. | Newcastle | J. H. SHAW: "The Use of High-pressure and High-temperature Steam in Large Power Stations." |
| 10 Dec. | Leeds | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| 10 Dec. | Manchester | Address by the President. |
| 10 Dec. | Glasgow | J. H. SHAW: "The Use of High-pressure and High-temperature Steam in Large Power Stations." |
| 13 Dec. | Dublin | S. L. R. PRICE: "A Few Notes on Electric Heating and Cooking." |
| 16 Dec. | Glasgow | Address by the PRESIDENT. |
| 18 Dec. | Birmingham | P. HUNTER-BROWN: "Carbon Brushes: considered in relation to the design and operation of electrical machinery." |
| 1919. | | |
| 14 Jan. | Leeds | P. HUNTER-BROWN: "Carbon Brushes: considered in relation to the design and operation of electrical machinery." |
| 14 Jan. | Manchester | LI. B. ATKINSON: The Tenth Kelvin Lecture: "The Dynamical Theory of Electric Engines." |
| 14 Jan. | Edinburgh | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| 20 Jan. | Newcastle | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |
| 27 Jan. | Cardiff | (To be announced later.) |
| 28 Jan. | Manchester | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| — Jan. | Birmingham | (To be announced later.) |

### STUDENTS' SECTION.

| *Date.* | *Place and Time of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 1918. | | |
| 10 Dec. | Finsbury Technical College (7 p.m.). | M. R. JAMES: "Marine Electric Propulsion." |
| 1919. | | |
| 24 Jan. | Northampton Polytechnic Institute (7 p.m.). | H. T. BODY: "A General Outline of Telephony." |

### VISITS TO WORKS.

| *Date.* | *Time.* | *Works to be Visited.* |
|---|---|---|
| 1918. | | |
| 18 Dec. | 2.30 p.m. | Osram-Robertson Electric Lamps Company, Hammersmith, S.W. |
| 1919. | | |
| 25 Jan. | 2.30 p.m. | Victoria Telephone Exchange, Westminster, S.W. |

Students who desire to take part in the above visits are requested to send in their names to the Hon. Secretary of the Students' Section, Mr. R. L. SMITH-ROSE, 76, Maryon-road, Charlton, S.E. 7.

## New Members of Council.

The Council have elected Mr. Percy R. Allen and Mr. Walter Judd to be Members of Council in place of the late Mr. J. O. Callender and the late Lieut. W. L. Preece, respectively.

## Honorary Member.

The Council have elected Professor A. E. Kennelly, D.Sc., M.A., of Harvard University, U.S.A., to be an Honorary Member of the Institution.

## Western Centre.

The Council have agreed to include in the above Territorial Centre the whole of the counties of Pembroke, Radnor, Cardigan, Carmarthen, Brecknock, Gloucester, and Hereford.

## Territorial Centres.

The President having visited and addressed meetings at the Scottish and each of the English Territorial Centres desires to express his sincere thanks to the Chairmen, the Committees, the Honorary Secretaries, and the members generally for the cordial reception accorded to him in every instance, as well as his high appreciation of the manifest interest in the work of the Institution. It is most gratifying to find that the action taken by the Council last Session in the direction of increasing the status, responsibility, and powers of the former Local Sections is already bearing such abundant fruit, and the benefit to the Institution as a whole can hardly be overestimated. The fundamental idea of the Council was that the Institution has no Sections but is one and undivided in whatever part of the country a meeting be held, and it is clear that the steps taken by them to give effect to this idea are already meeting with a large measure of success; this can only be complete if every individual member realizes his responsibility and gives loyal and strenuous support to the Institution. If this be done a brilliant future for it is assured.

The President hopes early in January to complete his round of visits by proceeding to Ireland and investigating on the spot the needs of members resident in that country.

## Model General Conditions for Contracts.

*Alteration to Clause* 24.—In the case of Contracts made on and after the 1st January, 1919, the amounts of the instalments of the retention money specified in Clause 24 (2) will be altered from 10 per cent and 10 per cent to 15 per cent and 5 per cent respectively.

## Electrical Power Engineers' Association.

The Council have decided to recognize officially the above Association as the protective Association for engineers qualified to hold a responsible position directly concerned with the production, transmission, distribution, or utilization of electrical energy.

The Council have also adopted the five resolutions (see *Institution Notes*, No. 8, p. 35, July 1918) passed at the Conference of representatives of the Associated Municipal Electrical Engineers of Greater London, the Chief Technical Assistants' Association, and the Electrical Power Engineers' Association held on the 9th July, 1918.

## Direct Current.

The Council have decided that the expression "direct current" shall be used in place of "continuous current" in all official publications of the Institution, including papers and the reports of discussions published in the *Journal*.

## Committees 1918–19.

Among the Committees appointed by the Council for 1918–19 are the following:—

### LIBRARY AND MUSEUM COMMITTEE.

The President.

Mr. H. H. Harrison.
Mr. K. Hedges.
Mr. J. E. Kingsbury.
Mr. W. M. Mordey.
Mr. J. Sayers.
Mr. A. P. Trotter.

### RESEARCH COMMITTEE.

The President.

Mr. Ll. B. Atkinson.
Mr. A. S. Barnes.
Mr. C. J. Beaver.
Sir R. T. Glazebrook, C.B., F.R.S.
Sir R. A. Hadfield, F.R.S.
Mr. H. H. Harrison.
Mr. J. S. Highfield.
Mr. W. Judd.
Prof. E. W. Marchant, D.Sc.
Prof. T. Mather, F.R.S.
Mr. C. H. Merz.
Mr. W. M. Mordey.
Mr. G. S. Ram.
Dr. A. Russell.
Sir W. Slingo.
Mr. C. P. Sparks.
Mr. J. Swinburne, F.R.S.
Mr. A. P. Trotter.
Prof. E. Wilson.
Mr. W. B. Woodhouse.

### "SCIENCE ABSTRACTS" COMMITTEE.

The President.

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Prof. E. W. Marchant, D.Sc.
*And*
Mr. W. R. Cooper.
Prof. J. W. Nicholson.
Mr. W. M. Mordey.
Mr. C. C. Paterson, O.B.E.
*Representing*
The Physical Society of London.

### SECTIONAL COMMITTEES.

#### Electric Traction.

The President.

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Mr. H. W. Firth.
Mr. F. Lydall.
Mr. A. H. W. Marshall.
Mr. G. W. Partridge.
Mr. H. I. Rogers.
Mr. J. Sayers.
Mr. R. T. Smith.
Mr. A. P. Trotter.

**Electricity in Mines.**

The President.

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| Mr. H. W. Clothier. | Mr. J. H. Rider. |
| Mr. W. C. Mountain. | Mr. C. P. Sparks. |
| Mr. R. Nelson. | Mr. J. P. Tierney. |

Mr. W. B. Woodhouse.

**Electro-Chemistry and Electro-Metallurgy.**

The President.

| | |
|---|---|
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| Mr. J. Christie. | Mr. W. M. Morrison. |
| Mr. W. R. Cooper. | Mr. C. P. Sparks. |
| Sir R. A. Hadfield, F.R.S. | Mr. T. Stevens. |

Mr. J. Swinburne, F.R.S.

**Lighting and Power.**

The President.

| | |
|---|---|
| Mr. R. A. Chatlock. | Mr. G. W. Partridge. |
| Mr. H. W. Clothier. | Mr. H. F. Proctor. |
| Mr. J. S. Highfield. | Mr. F. Samuelson. |
| Mr. A. Page. | Mr. C. P. Sparks. |

Mr. B. Welbourn.

**Telegraphs and Telephones.**

The President.

| | |
|---|---|
| Mr. H. G. Brown. | Mr. F. Ryan. |
| Mr. F. Gill. | Mr. J. Sayers. |
| Mr. H. H. Harrison. | Sir W. Slingo. |

**SHIP ELECTRICAL EQUIPMENT COMMITTEE.**

The President.

| | |
|---|---|
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| Mr. B. M. Drake. | Captain A. P. Pyne. |
| Mr. A. Henderson. | Mr. T. A. Sedgwick. |
| Mr. J. W. Kempster. | Mr. S. G. C. Russell. |
| Mr. J. F. Nielson. | |

| *And* | *Representing* |
|---|---|
| Mr. W. S. Abell ... ... | Lloyd's Register of Shipping. |
| Mr. J. T. Milton ... ... | |
| Mr. H. H. Berry ... ... | British Electrical and Allied Manufacturers' Association. |
| Mr. C. Rodgers ... ... | |
| Mr. T. Carlton ... ... | Board of Trade. |
| Mr. W. Cross ... ... ... | Electrical Contractors' Association. |
| Mr. J. Foster King ... ... | British Corporation for the Survey & Registry of Shipping. |
| Mr. J. Lowson ... ... | Institution of Engineers and Shipbuilders in Scotland. Electrical Contractors' Association of Scotland. |
| Mr. A. W. Stewart ... ... | Institution of Naval Architects. |
| Mr. H. Walker ... ... | N.E. Coast Institution of Engineers and Shipbuilders. |

**TERRITORIAL CENTRES.**

The President.

| | |
|---|---|
| Mr. D. N. Dunlop. | Mr. G. W. Partridge. |
| Mr. J. S. Highfield. | Mr. C. C. Paterson, O.B.E. |
| Mr. J. E. Kingsbury. | Mr. W. R. Rawlings. |

(One vacancy) and the 7 Chairmen of Territorial Centres.

**WIRING RULES COMMITTEE.**

The President.

| | |
|---|---|
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| Mr. R. H. Campion. | Mr. S. W. Melsom. |
| Mr. R. H. Fletcher. | Mr. J. F. Nielson. |
| Mr. J. Frith. | Mr. G. H. Nisbett. |
| Sir R. T. Glazebrook, C.B., F.R.S. | Captain A. P. Pyne. |

| *And* | *Representing* |
|---|---|
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| Mr. J. F. W. Hooper ... ... | |
| Mr. B. M. Drake ... ... | Contractors (unofficially). |
| Mr. S. G. C. Russell ... ... | Fire Offices (unofficially). |
| Mr. A. L. Taylor ... ... | |
| Mr. H. H. Berry ... ... | British Electrical and Allied Manufacturers' Association. |
| Mr. J. R. Dick ... ... ... | |
| Mr. W. E. Gray ... ... | Cable Makers' Association. |
| Mr. C. P. Sparks ... ... | Conference of Chief Officials of London Electric Supply Companies. |
| Mr. W. R. Rawlings ... ... | Electrical Contractors' Association. |
| Mr. E. J. B. Lowdon ... ... | Electrical Contractors' Association of Scotland. |
| Mr. E. T. Ruthven Murray ... | Incorporated Association of Electric Power Companies. |
| Mr. J. Christie ... ... ... | Incorporated Municipal Electrical Association. |
| One other representative ... | |

## Representatives of The Institution on Other Bodies.

The following is a list of representatives of the Institution on other Bodies, and the dates on which they were appointed.

Bristol, University of:
Mr. H. F. Proctor (6 Dec., 1917).

Corrosion Committee of the Institute of Metals:
Mr. J. S. Highfield (4 Oct., 1917).

Electrical Research Committee:
Mr. C. C. Paterson, O.B.E. (4 Oct., 1917).
Mr. C. P. Sparks (4 Oct., 1917).
Mr. C. H. Wordingham, C.B.E. (4 Oct., 1917).

Engineering Standards Committee (Main Committee):
Col. R. E. Crompton (2 April, 1914).
Sir John Snell (2 April, 1914).
Mr. C. P. Sparks (2 April, 1914).

Ditto (Sectional Electrical Committee):
Mr. F. Gill (21 May, 1914):
Mr. J. S. Highfield (21 May, 1914).
Mr. R. T. Smith (21 May, 1914).
Mr. C. H. Wordingham, C.B.E. (18 Nov., 1915).
(One vacancy.)

Ditto (Sectional Committee on British Standards in Colonial and Foreign Trade):
Mr. C. P. Sparks (26 Oct., 1916).

Ditto (Sectional Committee on Machine Parts and their Gauging and Nomenclature):
Mr. J. H. Rider (8 Feb., 1917).

Engineering Training Organization, Council of:
Mr. C. H. Wordingham, C.B.E. (22 Nov., 1917).

Imperial College of Science and Technology, Governing Body:
Mr. C. H. Wordingham, C.B.E. (24 Jan., 1918).

International Illumination Committee, British National Committee :
Mr. F. Bailey (27 Nov., 1913).
Mr. K. Edgcumbe (27 Nov., 1913).
Mr. H. T. Harrison (27 Nov., 1913).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).
Prof. W. C. Clinton (13 Dec., 1917).
Metalliferous Mining (Cornwall), School of, Governing Body :
Mr. C. P. Sparks (23 Jan., 1913).
Ministry of Labour, Trade Advisory Committee for the Electrical Industry (Disabled Sailors and Soldiers) :
Mr. C. P. Sparks (4 Oct., 1917).
Munitions Inventions Department (Nitrogen Products Committee) :
Sir John Snell (12 Oct., 1916).
National Physical Laboratory, General Board :
Mr. C. H. Wordingham, C.B.E. (22 Nov., 1917).
Mr. R. T. Smith (26 Nov., 1914).
Radiography Joint Committee of Royal Society of Medicine :
Mr. C. H. Wordingham. C.B.E. (27 June, 1918).
Mr. J. S. Highfield (27 June, 1918).
Prof. T. Mather, F.R.S. (27 June, 1918).
Mr. A. A. C. Swinton (27 June, 1918).
Röntgen Society, Advisory Committee of, for British X-ray Industry :
Dr. W. H. Eccles (21 Feb., 1918).
Mr. J. E. Taylor (21 Feb., 1918).
Scientific and Industrial Research, Engineering Committee of Advisory Council for :
Mr. J. S. Highfield 19 March, 1916).
Scientific Societies, Conjoint Board of :
Mr. C. H. Wordingham, C.B.E. (21 Nov., 1918).
Mr. C. P. Sparks (21 Nov., 1918).
Ditto, Education Committee :
Dr. A. Russell (12 Oct., 1916).
Technical Societies of Canada, Joint Committee :
Mr. S. L. B. Lines (8 March, 1917).

## Roll of Honour.

(Eleventh List.*)

**Killed in Action.**

| | | |
|---|---|---|
| Cope, Gunner E. L. N. | Royal Horse Artillery | Student |
| Ponter, Lieut. H. W. F. | London Regiment | Student |
| Saltren-Willett, Lieut.-Col. A. J. | Royal Garrison Artillery | Associate |

**Accidentally Killed.**

| | | |
|---|---|---|
| Hopkinson, Major B., C.M.G., F.R.S. | Cambridge University O.T.C. | Member |

**Died.**

| | | |
|---|---|---|
| Claeys, Corporal W. R. E. | Belgian Army | Student |
| Davis, Lieut. V. O. I. | Royal Engineers | Member |

## Military Honours Awarded.

(Twelfth List.†)

**Distinguished Service Order.**

| | | |
|---|---|---|
| Bailey, Major H. | East Lancashire Regt. | Associate Member |

**Bar to D.S.O.**

| | | |
|---|---|---|
| Vignoles, Lieut.-Col. W. A., D.S.O. | Lincolnshire Regt. | Member |

**Military Cross.**

| | | |
|---|---|---|
| Beer, Captain R. G. | Royal Engineers | Associate Member |
| Bellamy, Lieut. L. C. F. | Royal Engineers | Associate Member |
| Burgess, Lieut. L. F. | Australian Engineers | Associate Member |
| Cross, Captain H. | Australian Imperial Force | Associate Member |
| Fisher, Lieut. R. E. S. | Royal Engineers | Associate Member |
| Roseveare, Major L. | Royal Engineers | Associate Member |
| Clapham, Lieut. C. F. | Army Service Corps | Associate |
| Cheel, 2nd Lieut. E. S. | Royal West Kent Regt. | Student |

**Distinguished Flying Cross.**

| | | |
|---|---|---|
| Hayne, Captain E. T., D.S.C. | Royal Air Force | Student |

**Military Medal.**

| | | |
|---|---|---|
| Lebedeff-Lessin, Sapper M. S. | Royal Engineers | Graduate |

**Croix de Guerre (French).**

| | | |
|---|---|---|
| Charley, Captain R. M., M.C. | Royal Air Force | Student |

**Chevalier de l'Ordre de la Couronne.**

| | | |
|---|---|---|
| Bingham, Lieut J. H. | General Staff | Graduate |

**Mentioned in Dispatches.**

| | | |
|---|---|---|
| Bellamy, Lieut. L. C. F., M.C. | Royal Engineers | Associate Member |
| Trench, Major A. H. C. | Royal Engineers | Associate Member |

## Members on Military Service.

(Seventeenth List *)

Members.

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Gunton, H. C. | Royal Engineers | Major |
| Jobson, R. H. T. | General List | Major |
| Judson, D. | Royal Welsh Fusiliers | Lieut.-Col. |

Associate Members.

| | | |
|---|---|---|
| Anderson, A. A. | Royal Air Force | Sergeant |
| Bluett, E. J. H. | Royal Air Force | 2nd Lieut. |
| Crowcroft, H. E. | Royal Air Force | Lieutenant |
| Dutton, T. M. | Royal Air Force | Captain |
| Earnshaw, W. | Royal Navy | Eng. Lieut.-Com. |
| Evans, C. H. S. | Royal Engineers | Lieut.-Col. |
| Garrard, E. E. | Royal Engineers | 2nd Lieut. |
| Garrett, W. B. | Royal Air Force | Captain |
| Hunt, W. S. | Royal Engineers | Lieutenant |
| Johnson, A. | Admiralty Staff | Eng.-Asst. |
| Myhre, E. | Inns of Court O.T.C. | Private |
| Newman, K. C. H. | Royal Air Force | 2nd Lieut. |

* See *Journal I.E.E.*, vol. 54, pp. 64, 447, and 675 ; vol. 55, pp. 55, 193, 325, and 537 ; and *Institution Notes*, No. 1, p. 3 ; No. 4, p. 15, and No. 7, p. 29.

† See *Journal I.E.E.*, vol. 54, pp. 306, 518, and 674 ; vol. 55, pp. 56, 193, 325, and 537 ; and *Institution Notes*, No. 1, p. 3 ; No. 4, p. 15 ; No. 6, p. 24 ; and No. 7, p. 30.

* See *Journal I.E.E.*, vol. 53, pp. 199, 326, 388, and 857 ; vol. 54, pp. 121, 403, 518, and 675 ; vol. 55, pp. 57, 194, 326, and 538 ; and *Institution Notes*, No. 1, p. 1 ; No. 4, p. 16 ; No. 5, p. 13 ; and No. 7, p. 30.

ASSOCIATE MEMBERS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Ogilvie, F. T. | R.N.V.R. | Lieutenant |
| Nicholas, S. W. | Royal Engineers | Captain |
| Pearson, H. A. | King Edward's Horse (attd. M.G.C.) | Actg. Capt. |
| Pudan, T. A. | Royal Air Force | Air Mechanic |
| Rhodes, W. J. | Royal Naval Dockyard | First Assistant |
| Shearing, G. | Royal Navy | Elec. Artificer |
| Smyth, A. | Australian Flying Corps | 2nd-Class Air Mechanic |
| Stephenson, E. F. | Royal Engineers | 2nd Lieut. |
| Webb, F. H. | Royal Field Artillery (attd. R.E.) | Lieutenant |
| Walker, N. S. | Royal Engineers | Captain |
| Welply, J. H. | R.N.V.R. | Sub-Lieut. |
| Young, J. | Royal Air Force | Captain |

ASSOCIATES.

| | | |
|---|---|---|
| Gardiner, J. S. | Australian Imperial Force | Sapper |
| Woodcock, W. E. | London Electrical Engineers, R.E. | Sergeant |

GRADUATES.

| | | |
|---|---|---|
| Andrew, D. C. | Royal Navy | Electrician |
| Aylott, H. J. | Royal Engineers | Lieutenant |
| Cooper, C. M. | Royal Engineers | 2nd Lieut. |
| Cressey, J. A. | Royal Air Force | 3rd-Class Air Mechanic |
| De Hollanda, R. | Brazilian Flying Corps | Lieutenant |
| Hamid, K. A. | Mesopotamian Exped. Force | Asst. Engineer |
| Hobgen, L. B. | Royal Air Force | 2nd Lieut. |
| Saltren-Willett, C. G. | R.N.V.R. | Sub-Lieut. |
| Thomas, F. | Royal Air Force | 2nd-class Air Mechanic |
| Tolley, H. J. | New Zealand Signal Coy. | Sapper |

STUDENTS.

| | | |
|---|---|---|
| Baird, W. | London Regt. | Rifleman |
| Balbi, C. M. R. | R.N.V.R. | Sub-Lieut. |
| Ball, E. H. | Royal Engineers | Cadet |
| Birch, H. | Royal Engineers | Lance-Corpl. |
| Breeze, R. B. | Royal Engineers | Sapper |
| Broughall, J. A. | University of London O.T.C. | Cadet |
| Buist, D. M. | Royal Air Force | Corpl.-Mech. |
| Burke, G. B. | Royal Air Force | 2nd-class Air Mechanic |
| Cass, A. C. | Royal Air Force | 3rd-class Air Mechanic |
| Collard, J. | Royal West Surrey Regt. | Private |
| Cowen, J. S. M. | Royal West Surrey Regt. | 2nd Lieut. |
| Dawson, C. | New Zealand Exped. Force | Private |
| Edwards, L. | R.N.V.R. | Sub-Lieut. |
| Gibson, H. J. | Tank Corps | Private |
| Green, L. E. | South African Infantry | Private |
| Greenhill, A. | London Electrical Engineers, R.E. | Sapper |
| Halford, W. C. J. | Royal Marine Light Infantry | Corporal |
| Ives, C. W. F. | London Regt. | Private |
| Lewis, H. J. | Royal Air Force | Lieutenant |
| Liddiard, H. W. C. | Royal Air Force | 3rd-class Air Mechanic |
| Martindale, R. R. | Army Ordnance Department | Lieutenant |
| Messer, W. G. | Royal Air Force | Air Mechanic |

STUDENTS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Rait, D. M. | Inns of Court O.T.C. | Private |
| Rawll, R. H. | Royal Air Force | 2nd Lieut. |
| Shepherd, J. E. | Royal Air Force | Cadet |
| Smith, W. F. | Royal Air Force | 3rd-class Air Mechanic |
| Thomsett, E. | Royal Air Force | 3rd-class Air Mechanic |
| Watson, T. | Royal Navy | Engine Room Artificer |
| Wellings, J. G. | Royal Garrison Artillery | Signaller |

## Promotions, Transfers, etc., of Members on Military Service.

(THIRTEENTH LIST.*)

MEMBERS.

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Hamilton, C. N. M. | Royal Garrison Artillery | Captain |
| Jenkin, C. F. | Royal Air Force | Lieut.-Col. |
| Michôd, P. D. | Royal Engineers | Lieut.-Col. |
| Monkhouse, S. E. | Royal Engineers | Lieut.-Col. |
| Olver, G. T. W. | Royal Engineers | Major |
| Pyke, L. | Royal Air Force | Captain |
| Rose, F. O. J. | Royal Garrison Artillery | Major |
| Saunders, E. S. | R.N.V.R. | Lieut.-Com. |
| Taylor, A. M. | Royal Air Force | Major |
| Webb, H. L. | General Staff | Lieut.-Col. |
| Williams, A. | Royal Air Force | Captain |

ASSOCIATE MEMBERS.

| | | |
|---|---|---|
| Anido, A. J. | London Electrical Engineers, R.E. | Captain |
| Atkinson, C. S. | Humber Fortress, R.E. | Lieutenant |
| Bailey, H., D.S.O. | East Lancashire Regt. | Major |
| Beer, R. G., M.C. | Royal Engineers | Captain |
| Belfield, S. C. | Royal Air Force | Captain |
| Bentley, C. W. | Royal Air Force | 2nd Lieut. |
| Berger, C. C. | Royal Engineers | Lieutenant |
| Berry, T. B. | Royal Engineers | Captain |
| Binyon, B. | Royal Air Force | Major |
| Booth, T. C. | Home Service Employment Coy. | Lance-Corpl. |
| Bowden, J., O.B.E. | Royal Engineers | Lieut.-Col. |
| Brazier, C. C. H. | Royal Engineers | Captain |
| Brook, R. V. C. | Royal Air Force | Major |
| Brown, H. | Royal Engineers | Major |
| Brown, T. A. | Royal Engineers | 2nd Lieut. |
| Bullpitt, K. D. | Tank Corps | Lieutenant |
| Caparn, E. T., M.C. | Royal Engineers | Captain |
| Carey-Thomas, H. | Royal Engineers | Lieut.-Col. |
| Clark, Alexander | Royal Air Force | Lieutenant |
| Cohen, B. S. | Royal Air Force | Captain |
| Colbeck, P. | Royal Air Force | Major |
| Cooch, H. | Royal Air Force | Captain |
| Cornelius, V. A. | Royal Engineers | 2nd Lieut. |
| Cottle, P. J., M.C. | Royal Engineers | Major |
| d'Andria, A. V., M.C. | Royal Engineers | Captain |
| Date, W. H. | Royal Air Force | Lieutenant |

* See *Journal I.E.E.*, vol. 54, pp. 307, 434, 570, and 675; vol. 55, pp. 59, 95, 327, and 530; and *Institution Notes*, No. 4, p. 8; No. 5, p. 11; No. 5, p. 19; No. 7, p. 30.

ASSOCIATE MEMBERS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Dermer, L. H. C. | Royal Engineers | Major |
| Dumjohn, F. P. | Royal Engineers | Company Sergt.-Major |
| Empson, A. W. | Royal Air Force | Captain |
| Fendick, A. C. | Army Ordnance Dept. | Captain |
| Foster, F. W. | Leicestershire Regt. | Lieut.-Col. |
| Francies, R. | London Electrical Engineers, R.E. | Lieutenant |
| Gaskins, F. W. | Royal Engineers | Li eutenant |
| Gordon, A. H. | Royal Engineers | 2nd Lieut. |
| Graty, T. R., M.C. | Royal Engineers | Captain |
| Gray, E. B. | Royal Air Force | 2nd Lieut. |
| Harding, P. H. | Royal Engineers | 2nd Lieut. |
| Harrop, D. | Royal North Lancashire Regt. | Captain |
| Hart, H. M. | Royal Engineers | Lieutenant |
| Hartley, G., M.C. | Lancashire Fusiliers | Lieutenant |
| Hasdell, J. S. | Royal Air Force | 2nd Lieut. |
| Hewson, F. T. | Royal Navy | Lieut.-Com. |
| Holland, H. N. | Army Service Corps | Major |
| Hooper, H. | Royal Air Force | Captain |
| Hughes, A. E. | Royal Engineers | Major |
| Hume, D. C. M. | Royal Air Force | Major |
| Hutton, J. C. | Royal Engineers | 2nd Lieut. |
| Jeffreys, T. W. | Royal Field Artillery | 2nd Lieut. |
| Johnson, A. M. | Royal Air Force | Corporal |
| Johnson, S. | Australian Engineers | Lieutenant |
| Kirkpatrick, K. J. | Royal Garrison Artillery | Lieutenant |
| Knighton, C. W. | Canadian Engineers | Lieutenant |
| Lee, H. B. | Royal Air Force | Lieutenant |
| McCall, G. W. | Royal Air Force | Sergeant |
| McCormick, B. | Royal Air Force | Captain |
| McDougall, A. | Royal Engineers | Lieutenant |
| McLoughlin, H. F. | Royal Air Force | Lieutenant |
| Manson, J. C. | Canadian Engineers | Captain |
| Martin, P. M. | London Electrical Engineers, R.E. | Sergeant |
| Marvin, E. M., M.C. | Royal Engineers | Major |
| Meade, J. H. | Royal Air Force | Lieutenant |
| Medforth, G. T. | Royal Engineers | 2nd Lieut. |
| Menzies, F. A., M.C. | Royal Engineers | Captain |
| Meredith, J. | Royal Field Artillery | Lieutenant |
| Mickelwright, W. R. | Royal Air Force | Sergeant |
| Moir, G. H. | Royal Air Force | Captain |
| Moore, T. | Royal Air Force | Lieutenant |
| Mullard, S. R. | Royal Air Force | Captain |
| Murray, J. C. | Royal Air Force | Captain |
| Newbnry, A. D. | Royal Air Force | Captain |
| Orloff, E. | Royal Engineers | 2nd Lieut. |
| Pate, W. | Argyll and Sutherland Highlanders | Captain |
| Pattman, J. H. | Royal Air Force | Lieutenant |
| Payne, J. V. | Army Service Corps | Corporal |
| Podmore, A., M.C. | Royal Engineers | Major |
| Pollard, A. F. C. | Royal Scots Fusiliers | Captain |
| Pope, W. G. T., M.C. | Royal Engineers | Captain |
| Poulton, F. C. | Army Ordnance Dept. | Actg. Capt. |
| Price-Hughes, H. A. | Royal Engineers | Lieutenant |
| Ransom, S. | Royal Air Force | Captain |

ASSOCIATE MEMBERS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Robertson, H., M.C. | Royal Air Force | Lieutenant |
| Ross, T. A. | Royal Air Force | Captain |
| Saunders, F. E. | Royal Engineers | Lieutenant |
| Smeeton, E. E. | Royal Engineers | 2nd Lieut. |
| Smellie, A. | Royal Air Force | 2nd Lieut. |
| Smith, S. B. | R.N.V.R. | Sub-Lieut. |
| Staniar, H. D. | Royal Air Force | Lieutenant |
| Suggate, C. F. D., M.C. | Army Ordnance Dept. | Major |
| Thomas, J. H. | Royal Engineers | Lieutenant |
| Thomas-Jones, R. D. | Royal Air Force | Captain |
| Trench, A. H. C. | Royal Engineers | Major |
| Turner, W. B. | Royal Garrison Artillery | Lieutenant |
| Udall, R. O. | Canadian Infantry | Corporal |
| Vine, L. N. | Royal Air Force | 1st-class Air Mechanic |
| Wade, C. | Army Service Corps | Lieutenant |
| Walker, F. M. | Army Service Corps | Lieutenant |
| Ward, E. J. | Royal Irish Regt. | Lieutenant |
| Wells, R. I. | Royal Air Force | Lieutenant |
| Wheeler, O. | Royal Army Medical Corps | Lance-Corpl. |
| Williamson, G. W., M.C. | Royal Air Force | Major |
| Wilson, J. L. | Royal Engineers | Captain |
| Wood, E. L. | Tank Corps | Captain |
| Wright, F. T. | Army Ordnance Dept. | Major |
| Young, J. | Royal Engineers | Major |

ASSOCIATES.

| | | |
|---|---|---|
| Brooks, E. | Royal Garrison Artillery | Lieutenant |
| Roemer, C. W. von | Royal Air Force | Major |

GRADUATES.

| | | |
|---|---|---|
| Alsford, C. J. R. | Royal Air Force | Captain |
| Arnold, A. | Royal Navy | Eng. Lieut. |
| Blackburn, H. A. | Royal Air Force | 2nd Lieut. |
| Bourne, G. | Royal Garrison Artillery | 2nd Lieut. |
| Elphick, E. de B. | London Electrical Engineers, R.E. | Sergeant |
| Hornblower, T. J. | Royal Engineers | Captain |
| Jockel, L. M. | London Electrical Engineers, R.E. | Staff Sergt. |
| Lawrence, F. H. | Royal Field Artillery | Captain |
| Nichols, G. R. | Royal Engineers | 2nd Lieut. |
| Otter, F. L., M.C. | Royal Engineers | Lieutenant |
| Schneidau, T. C. | Royal Air Force | Corpl.-Mech. |
| Sleigh, C. C. | Royal Air Force | Lieutenant |
| Stokes, W. G. | Divisional Engineers, R.N.D. | Actg. Sergt. |
| Stout, T. S. | Royal Engineers | 2nd Lieut. |
| Wynyard-Wright, V.L. | Indian Army Reserve of Officers | Captain |

STUDENTS.

| | | |
|---|---|---|
| Albrecht, E. C. | Royal Garrison Artillery | Lieutenant |
| Allan, G. A. | Royal Engineers | Pioneer |
| Baxter, W. M. | Royal Air Force | Corpl.-Mech. |
| Bell, H. G. | Lancashire Fusiliers, attd. R.E. | Captain |
| Bridge, A. | Royal Engineers | Lance-Corpl. |
| Canton, G. D. | Army Service Corps | Lieutenant |
| Carlisle, R. S. | Royal Air Force | Cadet |
| Charley, R. M., M.C. | Royal Air Force | Captain |
| Clifton, J. P. | Royal Artillery | Lieutenant |

STUDENTS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Colburn, F. | Royal Engineers | Sapper |
| Cook, P. H. | Royal Air Force | 3rd-class Air Mechanic |
| Cooke, H. R. | Royal Air Force | 2nd Lieut. |
| Coulthard, W. B. | London Electrical Engineers, R.E. | Lance-Corpl. |
| Damant, E. L. | Royal Engineers | Lieutenant |
| Davies, G. F. | Royal Engineers | 2nd Lieut. |
| Dawes, A. R. | London Electrical Engineers, R.E. | Corporal |
| Doran, W. E. | Royal Air Force | 2nd Lieut. |
| Dunnill, F. | Royal Engineers | 2nd Corpl. |
| Gardner, W.E., D.S.C. | Royal Air Force | Captain |
| Glover, E. H. | Royal Engineers | Captain |
| Grose, S. J., M.C. | Royal Field Artillery | Major |
| Hall, H. J. | Royal Air Force | 2nd-class Air Mechanic |
| Harris, E. L. H. | Australian Imperial Force | Sergeant |
| Harrison, A. | Royal Air Force | Captain |
| Hayne, E. T., D.S.C., D.F.C. | Royal Air Force | Captain |
| Hayward, F. H. | Royal Navy | Eng. Lieut. |
| Hindom, H. J. | Royal Air Force | Corporal |
| Hoseason, D. B. | Royal Engineers | Sapper |
| Iudkevitch, R. M. N. | Royal Engineers | Sergeant |
| Jones, V. A. | Royal Engineers | 2nd Lieut. |
| Lane, C. F. | Royal Engineers | Sergeant |
| Leeson, B. E. | Royal Air Force | Lieutenant |
| McWhinnie, D. R. | Royal Air Force | 2nd Lieut. |
| Mahon, B. E. | Royal Engineers | 2nd Lieut. |
| Mann, H. C. | Royal Air Force | 2nd Lieut. |
| Martin, G. E. | Royal Garrison Artillery | Captain |
| Metcalf, J. N. | Royal Engineers | Lance-Corpl. |
| Miller, N. H. | Royal Engineers | 2nd Lieut. |
| Murray, B. M. | London Electrical Engineers, R.E. | Lance-Corpl. |
| O'Brien, B. H. | Leinster Regt. | 2nd Lieut. |
| Ostler, P. | City of Edinburgh (Fortress) R.E. | Lieutenant |
| Perrin, J. F. | London Electrical Engineers, R.E. | Lieutenant |
| Peskett, E. G. A. | Royal Air Force | Lieutenant |
| Powell, C. A. W. | Royal Engineers | Lieutenant |
| Pullan, A. H. | Royal Engineers | Lieutenant |
| Puttick, H. W. | Royal Garrison Artillery | 2nd Lieut. |
| Rankin, D. A. | Royal Engineers | Lance-Corpl. |
| Richardson, W. | Royal Lancaster Regt. | 2nd Lieut. |
| Ross, G. M. | Royal Engineers | Actg. Major |
| Ross-Bain, G. | Royal Air Force | Captain |
| Rowe, B. | Manchester Regt. | Lieutenant |
| Sadler, C. W. C. | Royal Engineers | Corporal |
| Smith, C. P. | Royal Engineers | 2nd Corpl. |
| Travers, A. | Royal Air Force | Lieutenant |
| Trutch, C. J. H. | Royal Air Force | Captain |
| Underwood, C. L. | Royal Air Force | 2nd Lieut. |
| Wall, H. H. | Royal Air Force | Lieutenant |
| Webb, R. J. | Kent (Fortress) R.E. | Lieutenant |
| Wrigley, P. | Royal Engineers | Lieutenant |

INSTITUTION STAFF.

| | | |
|---|---|---|
| Ashford, H. J. | Royal Fusiliers | Corporal |
| Grant, F. | Royal Air Force | Sergeant |
| Rayner, A. E. | Army Service Corps | Sergeant |

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——— ——— ———. Summary report for the year ending Dec. 31, 1916. 8vo. 201 pp. *Ottawa*, 1917

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——. DEPARTMENT OF THE INTERIOR. BUREAU OF MINES. Monthly statement of coal mine fatalities in the United States. April, and May, 1917. List of permissible explosives, lamps, and motors tested prior to May 31, 1917, and to June 30, 1917. Compiled by Albert H. Fay. 2 vols. 8vo. *Washington*, 1917

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VINAL, G. W. Some electrical properties of silver sulphide. [U.S. Dept. of Commerce, Scientific papers of the Bureau of Standards, no. 310]. 8vo. 14 pp. *Washington*, 1917

WADSWORTH, J. M. Efficiency in the use of oil fuel. [U.S. Dept. of the Interior. Bureau of Mines]. sm. 8vo. 86 pp. *Washington*, 1918

WARD, H. Pocket dictionary of technical terms used in wireless telegraphy. 8vo. 170 pp. *London*, [1918]

WIG, R. J., *and others*. Durability of cement draintile and concrete in alkali soils. [United States, Dept. of Commerce, Technologic Papers of the Bureau of Standards, no. 95]. 8vo. 94 pp. *Washington*, 1917

WOLLASTON, T. R. Power plant. Installation, upkeep, and economical operation. 8vo. 117 pp. *London*, 1918

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 10. JANUARY 1919. INSTITUTION NOTES. [ISSUED WITH No. 278 OF THE JOURNAL.]

## Meetings for January and February 1919.

### ORDINARY MEETINGS OF THE INSTITUTION.

| *Date.* | *Author and Title of Paper.* |
|---|---|
| 1919. | |
| 9 Jan. | M. B. FIELD, O.B.E.: "The Navigational Magnetic Compass considered as an Instrument of Precision" (Lecture). |
| 23 Jan. | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |
| 13 Feb. | Lieut.-Col. W. A. J. O'MEARA, C.M.G.: "The Functions of the Engineer: His Education and Training." |
| 20 Feb. | G. L. ADDENBROOKE: Lecture on "Dielectrics." |
| 27 Feb. | Paper or papers on "The Co-ordination of Research in Works and Laboratories." |

### MEETINGS OF TERRITORIAL CENTRES.

| *Date.* | *Place of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 1919. | | |
| 14 Jan. | Edinburgh | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| 14 Jan. | Leeds | P. HUNTER-BROWN: "Carbon Brushes: considered in relation to the design and operation of electrical machinery." |
| 14 Jan. | Manchester | H. B. ATKINSON: The Tenth Kelvin Lecture: "The Dynamical Theory of Electric Engines." |
| 15 Jan. | Birmingham | C. JONES: "Current and Potential Transformers." |
| 20 Jan. | Newcastle | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |
| 27 Jan. | Cardiff | Lieut.-Col. W. A. J. O'MEARA, C.M.G.: "The Functions of the Engineer: His Education and Training." |
| 28 Jan. | Manchester | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| 5 Feb. | Birmingham | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |
| 10 Feb. | Newcastle | Professor MILES WALKER, D.Sc.: "The Supply of Single-phase Power from Three-phase Systems." |
| 11 Feb. | Glasgow | P. HUNTER-BROWN: "Carbon Brushes: considered in relation to the design and operation of electrical machinery." |
| 11 Feb. | Leeds | T. B. JOHNSON: Address on "The Leeds Automatic Telephone Exchange." |
| 11 Feb. | Manchester | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |
| 24 Feb. | Newcastle | Discussion on "The Wants of an Ordinary Household as regards Lighting, Heating, and Cooking." |
| 25 Feb. | Manchester | S. F. BARCLAY, Ph.D., and J. S. P. SMITH, D.Sc.: "The Determination of the Efficiency of the Turbo-Alternator." |

### STUDENTS' SECTION.

| *Date.* | *Place and Time of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 1919. | | |
| 24 Jan. | Northampton Polytechnic Institute (7 p.m.). | H. T. BODY: "A General Outline of Polytechnic Telephony." |
| 7 Feb. | Finsbury Technical College (7 p.m.). | R. P. HOWGRAVE-GRAHAM: "Oscillatory Electric Discharges." (Experimentally-illustrated lecture.) |

### VISITS TO WORKS.

| *Date.* | *Time.* | *Works to be Visited.* |
|---|---|---|
| 1919. | | |
| 25 Jan. | 2.30 p.m. | Victoria Telephone Exchange Westminster, S.W. |
| 15 Feb. | 10 a.m. | Marconi's Wireless Telegraph Co. Chelmsford; The Hoffmann Manufacturing Co. Chelmsford. |

Students who desire to take part in the above visits are requested to send in their names to the Hon. Secretary of the Students' Section, Mr. R. L. SMITH-ROSE, 31 Fairlawn-avenue, Chiswick, W. 4.

## Informal Dinners after Ordinary Meetings.

In order to enable the necessary arrangements to be made, members wishing to dine together at the Waterloo Restaurant, Charles-street, Haymarket, S.W., after the Ordinary Meetings are asked to send their names to the Institution Offices not later than the Wednesday morning preceding the Meeting. Owing to food difficulties the proprietor of the Restaurant is unable to cater for an unspecified number of visitors.

## Leeds Technical Library.

Mr. W. B. Woodhouse has been nominated to be the representative of the Institution on the Leeds Technical Library Committee.

## Founding of the Institution.

Mr. A. H. Preece has presented to the Institution the original of a letter, dated 26th January, 1871, from the late Major Frank Bolton to the late Mr. R. S. Culley in regard to the founding of the Society of Telegraph Engineers. The letter is as follows :—

2, Westminster Chambers, Victoria Street, S.W.
London, 26 *January*, 1871.

DEAR SIR,

In acknowledging with thanks your note of the 25th instant I would observe that after carefully considering the matter of the proposed Society, with Siemens, L. Clark, Sabine, and several others, in the active part of the profession, I am convinced that not only has the time come for the formation of such a Society but that had some years ago a similar Society been properly conducted, it could even then not have failed to fulfil an important mission. On the other side I send you as you desire the names of those gentlemen who have already notified their desire to join. You will perceive that since writing to you several names have been added.

Trusting to receive your co-operation,

I am, Faithfully yours,

FRANK BOLTON.

R. S. Culley, Esq.

| | |
|---|---|
| Andrews. | Eggington. |
| Anderson, R. E. | Forde. |
| Becker. | Fletcher. |
| Bartholomew. | Fitzgerald. |
| Bolton. | Greener. |
| Barrow. | Graves. |
| Beaumont, R.E. | Higgs |
| Collett. | Lundy. |
| Lord Cecil (Sackville). | Langdon. |
| Canning. | Lord Lindsay. |
| L. Clark. | Preece. |
| Preece, G. | Scudamore. |
| Phillips. | Thuler. |
| Phillips, S. | Taylor. |
| Radcliffe. | Varley. |
| Smith. | Varley, O. |
| Shaw. | Webb. |
| Spagnoletti. | Webber. |
| Sack. | Whitehouse. |
| Siemens | Ritso. |
| Siemens, C. | Lendi. |
| Stotherd, R.E. | Moxon. |
| Sabine. | |

*Note.*—About 150 gentlemen have been written to on the subject, but 75 have only had their letters since the 23rd instant and this date.—F. B.

## Discussions on Wiring and Installation Work.

The Council have decided to make arrangements for discussions on subjects of interest to wiring contractors and their assistants, and the following Committee has been appointed for that purpose :—

The President (*ex officio*).

Mr. Ll. B. Atkinson. Mr. J. E. Kingsbury.

Mr. J. H. Cash, } Electrical Contractors' Association.
Mr. W. R. Rawlings, }

Mr. J. S. Highfield, } Association of Supervising Electricians.
Mr. C. J. Banister, }

## Professor A. E. Kennelly.

The following biographical note in regard to Professor Kennelly, D.Sc., who was recently elected an Honorary Member of the Institution (see *Institution Notes* No. 9, page 1), will be of interest to members :—

Professor Kennelly was born on the 17th December, 1861, in Bombay, where his father was harbour master. He was educated at University College School, London. As a youth, he was for a year on the staff of the Institution (at that time the Society of Telegraph Engineers), and in 1877 he was appointed to a clerkship in the service of the Eastern Telegraph Company, shortly afterwards becoming assistant electrician on board the s.s. *Great Northern*, and subsequently chief electrician of various ships of the Company's fleet. In 1888 he obtained an appointment in Mr. T. A. Edison's laboratory, and in 1894 took up consulting work in Philadelphia, with Professor E. J. Houston. In 1902 he was appointed Professor of Electrical Engineering at Harvard University, a position which he still holds, in addition to carrying on his consulting practice.

He joined the Institution in 1884 as an Associate and was transferred to full membership in 1894. He was awarded the Institution Premium in 1887 for a paper on "The Resistance of Faults in Submarine Cables," and

the Fahie Premium in 1889 for a paper entitled "Certain Phenomena connected with Imperfect Earth in Telegraph Circuits."

He is a Past President of the American Institute of Electrical Engineers, of the Illuminating Engineers Society, and of the Institute of Radio Engineers. He was General Secretary of the International Electrical Congress of St. Louis in 1904 and a Vice-president of the International Electrical Congress of Paris in 1900. He is the Secretary of the American Committee of the International Electrotechnical Commission, an Honorary Member of the National Electrical Light Association and of the New York Electrical Society. He is a Corresponding Member of the British Association for the Advancement of Science. He is the Director of Electrical Engineering Research of the Massachusetts Institute of Technology, and has received two medals from the Franklin Institute of Philadelphia for electrical researches.

## Books for Serbian Libraries.

The Council have received an application from the Information Bureau for Serbian Relief for copies of British textbooks on engineering for the Serbian technical libraries to replace those (mostly German) damaged or destroyed during the War. Members who have copies of such works which they can spare for this purpose are invited to forward them to the Secretary of the Institution, at 1, Albemarle-street, W. 1, marked "Serbian Technical Libraries."

The Council have decided to present a set of bound volumes of the Institution *Journal* for the last 20 years and books to the value of £50.

## Board of Trade Report on Electric Power Supply.

At a meeting held on the 9th January, 1919, the Council approved the following letter which had been sent to Sir Albert Stanley, P.C., M.P., President of the Board of Trade, by the B.O.T. Electricity Reports Committee of the Institution (see *Institution Notes*, No. 8, page 33, July, 1918).

The Institution of Electrical Engineers,
1, Albemarle Street, W. 1.
1 *January*, 1919.

The Rt. Hon. Sir Albert H. Stanley, P.C., M.P.
President of the Board of Trade,
7, Whitehall Gardens, S.W. 1.

*Electric Power Supply.*

SIR,

1. On the 27th day of June, 1918, the Council of the Institution of Electrical Engineers took into consideration the Reports of the Committees appointed by the Board of Trade on Electric Power Supply (Cd. 9062) and Electrical Trades after the War (Cd. 9072).

2. These Official Reports embody recommendations leading to drastic revisions of the conditions under which the electrical supply industry had been carried on in Great Britain. Recognizing that the future course of development in electricity supply for industrial and domestic purposes, in electric traction, in electrical manufacturing, and in many other branches of electrical business depended on the character of the legislation based upon these Reports, the Council were convinced that the Institution of Electrical Engineers, as the body including and representing those engaged in all sections of the electrical industry, should endeavour to obtain and to collate the opinions of these sections on the fundamental issues involved.

In view of the vital importance of a cheap and abundant supply of electricity to the engineering and other industries the Council decided to form a special Committee and to include therein representatives of the most important consumers of electric power.

3. Each of the following bodies was invited to nominate two representatives, who with the President and four Vice-Presidents of the Institution of Electrical Engineers acting *ex-officio* would constitute the Committee :—

The British Electrical and Allied Manufacturers' Association.
The Association of Consulting Engineers.
The Federation of British Industries.
The Cable Makers' Association.
The Incorporated Association of Electric Power Companies.
The Provincial Electric Supply Committee of the United Kingdom.
The Tramways and Light Railways Association.
The British Electrical Federation Limited.
Edmundsons' Electricity Corporation Limited.
The Iron and Steel Institute.
The Conference of Directors of the London Electric Supply Companies.
The Electrical Contractors' Association.
The Incorporated Municipal Electrical Association.
The Association of Municipal Corporations.

4. At a preliminary meeting of the Committee held on the 29th July, 1918, it was agreed that each Association represented should give separate and independent consideration to the Reports of the two Board of Trade Committees, and should draw up their recommendations as to the main lines which future legislation should follow. The Incorporated Municipal Electrical Association and the Association of Municipal Corporations had, however, decided to submit separate Reports to the Board of Trade, and were not represented on the Committee.

5. The Reports of the remaining Associations were duly prepared and laid before the Committee, after having been adopted in most cases by the respective Councils of the Associations. They accordingly embody the considered opinions of the accredited representatives of several large groups of electric supply

undertakings, the great majority of electrical manufacturers, consulting engineers, and the most important users of electric power for industrial purposes in Great Britain.

6. Some of the Reports were less detailed than others, and it is therefore not possible to present a combined opinion upon all the matters dealt with by the two Committees of the Board of Trade. On no point of primary importance, however, is any material difference of opinion displayed. Substantially on the main issues relating to present electrical legislation the various Associations showed an impressive unanimity.

7. The following views and recommendations in regard to Electric Power Supply more particularly are therefore presented as expressing the united convictions of the Committee and through them of the many sections of industry which they represent :—

(*a*) The restrictive conditions embodied in the Electric Lighting Acts, the Tramways Act, the Light Railways Act, and the various Acts relating to electric power supply have had a most detrimental effect on electrical progress in Great Britain. This legislation has led to the multiplication of small, arbitrary, and uneconomical areas of electricity supply and systems of electric traction ; it has discouraged the investment of capital in electrical undertakings by imposing limited tenure with unattractive terms of expropriation and various other onerous conditions ; it has placed obstacles in the way of grouping undertakings into comprehensive systems of supply and transport ; it has, generally, prevented British electrical engineers and manufacturers from realizing in their own country the highest achievements of which their technical skill and productive capacity were capable, and it has in consequence put them under a serious handicap in the competition for export business against countries in which the conditions have been more favourable for successful commercial demonstration.

(*b*) The evil effect of past legislation, emphasized so strongly by both the Official Reports, necessitates drastic reform of the enactments referred to, both in the spirit and in the letter, if the industry is to fulfil its function of providing cheap and abundant electricity for industrial, agricultural, and domestic purposes, and for the development of electric traction on railways, light railways, and roads.

(*c*) In addition to releasing electrical enterprises from the existing disabilities, the chief necessities of the situation are (1) the treatment of the problem of electrical generation and distribution on broad lines, and (2) the provision of simple forms of procedure in obtaining powers for electrical utilities of all kinds

(*d*) In order to secure these and other essentials of ordered progress, the proposed appointment of a Board of Electricity Commissioners is welcomed subject to the provisions expressed below.

(*e*) The Committee are strongly convinced that, owing to the complexity of the technical, administrative, and financial problems involved in a comprehensive scheme of electric supply reform, it will be found altogether impracticable to deal directly with the task of reconstruction by means of general legislation covering all the points at issue. They accordingly urge that immediate action should be confined to the creation of the Board of Electricity Commissioners, who should have powers and functions as outlined in the following paragraphs. There should be a gradual development in the establishing of the administrative machinery as the necessity is felt, otherwise the industry may be hampered in the future by excessive organization, to the same extent as it has been in the past by the conditions which have been referred to.

(*f*) This Board should be a tribunal of skilled men, free from political influence, charged generally with the duties of (1) examining all proposals for the extension and consolidation of existing electrical enterprises ; (2) recommending to the Board of Trade and to Parliament, for authorization, schemes which are on the soundest financial and engineering lines, and (3) advising the Government on legislative matters for the encouragement of the electrical industry.

(*g*) The functions of the Board should be exclusively judicial and advisory. Strenuous objection is urged against the granting to the Board of administrative powers over electrical undertakings and also of authority to appoint District Boards in the event of such bodies being constituted. In this respect the powers of the Commissioners should be limited to examining schemes brought before them for dealing with the various districts.

(*h*) The preparation of such schemes, whether company, municipal, or joint, should be left as a matter of free and natural development to the initiative of Undertakers who would formulate such schemes (it may be rival schemes) and put them forward for the consideration of the Commissioners, who would report to Parliament upon any Bills intended to carry them into effect. Opponents would be entitled to be heard against such Bills in the usual way.

(*i*) The Board may be empowered to deal with the Electrical Rules and Regulations administered by the Board of Trade and the Home Office, and it may also act as arbitrator and as a Court of Record for the electrical industry.

(*j*) The Railway and Canal Commission is suggested as a general model for the constitution and powers of the Board.

(*k*) The number of Commissioners on the Board should be five, and in all cases the appointments should be permanent, or for long periods, and should be on such conditions as will

attract men of the highest ability, knowledge, and independence. One member should be skilled in legal affairs and in sifting evidence, one in finance, one in the problems of electrical manufacture, and the others with experience in engineering and the management of electrical undertakings.

(*b*) While in the main the work of the Board will consist of formulating the principles of procedure in the course of electrical progress, and of recommending the legislative amendments and the specific schemes which are in agreement with these principles, it may be necessary in some cases for the Board to propose the enforcement, by Parliamentary authority, of arrangements for interconnection or amalgamation of supply undertakings.

8. Recommendations have been made by various Associations represented on the Committee regarding specific matters dealt with in the Reports of the two Board of Trade Committees, but it is felt that these problems will receive a satisfactory solution as a result of the formation of an independent authoritative Board of Electricity Commissioners, which is the crucial matter at this stage.

I am directed respectfully to urge on behalf of the Committee that legislation adverse to the views of the large proportion of the industry and of the consumers which the Committee represents may not be introduced without their being accorded an opportunity of discussing the matter with you.

I have the honour to be, Sir,
Your obedient Servant,

(Signed) P. F. Rowell, Secretary I.E.E.
On behalf of the Committee.

## Epitome of Mr. G. L. Addenbrooke's Lectures on Dielectrics in Electric Fields.

*(Lectures to be delivered before* The Institution, *20th February, and 6th and 13th March,* 1919.)

The subjects which will be chiefly considered in these lectures are as follows:

1. Short history of thought on the nature of dielectric actions.

2. The measurement of the effects in electrical fields, steady and alternating, and the best form of unit in which to express them.

3. Tables showing the specific relative losses in steady and alternating fields for a wide range of dielectrics. These show an evident connection between the steady field losses and those with alternating fields. Also a great difference in range between the d.c. and a.c. losses over the full range of dielectric substances, and increasing differences between the d.c. and a.c. losses as these become smaller or the dielectrics have higher resistances

4. The character of surface-leakage losses with steady and alternating fields, with comparative table. The similarity of their characteristics to those of the losses through dielectrics.

5. Examples giving a general idea of what these losses mean in practice, in power supply, telegraphy, telephony, and wireless telegraphy.

6. The development of these losses at moderate pressures up to breakdown pressure, and their influence in breakdown, with example.

7. An attempt to show quantitatively in its different aspects the progress of breakdown in a mechanically perfect dielectric, which seems to lead to the inference that the antecedent causes are purely heat effects, having a strong cumulative tendency.

8. The cumulative effect of this electric heating in developing faults at weak spots in dielectrics.

9. General experimental evidence showing that the losses and changes of capacity with change of frequency both in steady and alternating fields vary greatly according to the percentage of moisture present, in so-called pervious dielectrics, including the mineral oils. (Examination shows that by far the larger and more important classes of materials used in practice come under the heading of pervious dielectrics.)

10. From the close similarity of the curves of losses and capacity actions in steady and alternating fields in materials like glass and mica to those obtained with pervious dielectrics, the inference seems warranted that the same causes fundamentally underlie the actions occurring in these materials also. Apparently, therefore, in both classes of dielectrics we are up against similar actions having similar root causes.

11. In all cases where losses are present there are variations of capacity with frequency also.

12. The variation of capacity with frequency is also greatly altered by altering the amount of moisture present in pervious dielectrics. The magnitude of the change always varies with that of the losses

13. The change of capacity with frequency is of the same character in glass, mica, etc., as in admittedly pervious dielectrics

14. When the a.c. losses are large the variation of capacity with frequency is large also; when small the variation of capacity is small also. No exception to this rule has been found in tests on a large number of dielectrics.

15. The evidence seems decisive that these variations of capacity with frequency are an integral part of the same action which gives rise to the losses

16. Experiments on a representative dielectric showing:

(*a*) The variations which are caused in the capacity actions in an alternating field when the amount of moisture present is increased progressively from a minimum by definite amounts, ascertained by weighing the dielectric in a dry atmosphere before each experiment.

(*b*) The alternating and steady field losses under the same conditions as in (*a*) and which are complementary to the variations in the capacity actions shown in (*a*)

17. These experiments show that as a dielectric is more and more freed from moisture or free electrolyte the capacity or energy stored and the losses or energy dissipated tend downwards to a limit. This limit appears to be zero or appreciably so for the losses. For the capacity or stored energy the limit appears to be the true molecular energy storage of the molecules of the material itself, which corresponds to its true dielectric constant.

18. The above experiments indicate that the percentage of moisture present in a given dielectric can apparently be deduced from electric measurements only, by proper preliminary experiments.

19. The alteration of the actions in dielectrics with increase of temperature gives rise to phenomena of extraordinary interest; the effects are complicated but exceedingly suggestive. All the effects when moisture is present are very large as compared with the effects produced by temperature on most other physical actions, with two or three significant exceptions.

20. It seems probable the vapour pressure of water at different temperatures and pressures is not unconnected with the above phenomena and may even be the fundamental cause of the effects found combined with difference of osmotic pressure.

21. Provided moisture could be extracted from pervious and other dielectrics to a greater degree than is accomplished in practice at present, and that this could be done without detriment to the mechanical properties of these substances, the results seem to indicate that very superior dielectrics could be produced less subject to breakdown. This, however, also implies that the moisture could be kept out afterwards.

22. The final or limiting capacity of definite and pure materials when moisture or other extraneous electrolyte is absent appears to be a typical physical attribute of the matter of each individual substance, element or compound.

23. It will be shown that when the dielectric constants of a large number of elements and compounds are plotted on squared paper using those dielectric constants as ordinates and certain other physical properties as abscissæ, a definite grouping of the substances plotted becomes manifest.

24. It also seems clear that this grouping is on a basis of $K-1$ and not of $K$ (the dielectric constant). That is, that the pure ether storage must be first deducted before comparing the energy storage depending on the presence of the molecules of each material itself.

25. It will be shown that on this basis the true dielectric effects or $(K-1)$ of substances are apparently primarily dependent on (1) density; (2) atomic weight; (3) position in the Periodic Table, which would imply a connection with valency. In addition to the known connection with the refractive index in the case of elements and many compounds.

26. It will be shown further that apparently there is an inter-relation between the dielectric constants of substances and their specific heats.

27. The value of the modern theory of the electronic and ionic constitution of matter, in providing a plausible explanation of these actions.

## Addresses Wanted.

The present addresses of the following members are required for the Institution Register:—

MEMBERS.

| *Name.* | *Last Address.* |
|---|---|
| A. M. Coombs | 31, Charing Cross, S.W. 1. |
| C. W. Durnford | 4, St. Stephen's Avenue, Ealing, W. |
| L. H. S. Ellson | 345, St. George's Terrace, Perth, W. Australia. |
| R. E. Fletcher | Grosvenor, Church Street, Devonport, Auckland, New Zealand. |
| P. D. Ionides | 124, St. Vincent Street, Glasgow. |
| A. Jourdan | Chez M. Paul Talon, Zone du village, à Marseilles, France. |
| T. A. Locke | 8, Thurloe Road, Worthy Lane, Winchester. |

ASSOCIATE MEMBERS.

| | |
|---|---|
| W. Mc. L. Arnot | Messrs. Siemens Bros. Dynamo Works Ltd., 42, Bridge Street, Sydney, Australia. |
| F. C. D. Atkin | Usine Electrique, Municipalité de Beni-Souef, Egypt. |
| A. M. Atkinson | Ashford, Kent. |
| H. Bingham | 23, Newcomen Street, Newcastle, New South Wales, Australia. |
| F. Blair | 105, Castlenau, Barnes, S.W. 13. |
| W. R. Brown | 66, Lordship Lane, Dulwich, S.E. |
| C. A. Butlin | Lista de Correos, San Juan de Porto Rico, South America. |
| C. F. Button | 28, Glebe Road, Peterborough. |
| W. R. Cooper | 217, Kenmure Street, Pollokshields, Glasgow. |
| F. B. Cramer | 48, Maple Road, Surbiton. |
| G. K. Field | c/o the Norma Motor & Engineering Co., Ltd., 1, Lanfranc Street, Westminster Bridge Road, S.E. 1. |
| W. A. Fitzgerald | 13, Malbrook Road, Upper Richmond Road, Putney, S.W. 15. |
| H. C. Heath | Cleveland Street, Burslem, Staffs. |
| D. Jackson | G. P. O. Testing Branch, Mount Pleasant, E.C. |
| G. Johnson | 80, Pendarves Road, Tuckingmill, Cornwall. |
| Z. D. King | 423, Chekiang Road, Shanghai. |
| E. H. Leonardt | 163, Howard Road, Walthamstow, N.E. |
| M. B. Lugan | 322, Donald Street, Winnipeg, Canada. |
| M. E. Macdonald | Rosherville Power Station, Cleveland, Transvaal. |
| A. W. Maley | Westbourne Road, New Inns, Handsworth, Birmingham. |
| N. M. Marshall | Canada Buildings, Bombay, India. |
| A. A. Maytham | Maytham Tin & Steelware, Ltd., East London, South Africa. |
| T. Mills | c/o Messrs. Spencer & Co., Ltd., Melksham. |
| W. H. Moore | Superintendent Engineer to Port Commissioners, Calcutta, India. |
| J. Murray | Cheam Cottage, Summerley Road, Kenilworth, Cape Colony. |

ASSOCIATE MEMBERS—*continued.*

| *Name.* | *Last Address.* |
|---|---|
| C. E. F. Parker | Elmside, Elmhurst Road, Gosport. |
| R. B. Perring | Dickapitiya, Haputale, Ceylon. |
| E. Probert | 820, Central Building, Sixth and Main Streets, Los Angeles, Cal., U.S.A. |
| T. A. Pudan | 68, Schlusseburg Road, Petrograd, Russia. |
| J. I. Robertson | 5, Bruntsfield Gardens, Edinburgh. |
| R. J. Rosser | Corporation Electricity Works, Dock Road, Cape Town. |
| H. Rust | 80, Moniea Grove, Levenshulme, Manchester. |
| W. Ryley | "Clandalough," Plough Lane, Purley. |
| A. Sadler | c/o Messrs. Huttenbach & Co., Penang, Straits Settlements. |
| C. E. Savage | Sedgley, Worcester. |
| E. Sayer | 27D, London Road, Forest Hill, S.E. |
| C. H. Shanan | Maple Hayes, Mussoorie, U.P., India. |
| C. W. Shepherd | Royal Holloway College, Englefield Green S.O., Surrey. |
| M. W. Staight | Messrs. The Ga. Fuller Co., Ltd., Montreal, Canada. |
| J. D. A. Vincent | 9, Lansdowne Street, Withington, Manchester. |
| J. A. W. Ward | 14, Goodmayes Road, Goodmayes, Essex. |
| A. B. Wearing | Canadian Union Electric Co., Ltd., 130, Wellington Street West, Toronto. |
| A. G. Whitfield | Public Works Department, Taiping, Perak, F.M.S. |
| A. E. Wilkins | 13, Belvedere Place, Dublin. |
| R. D. Wolfgang | The West India and Panama Telegraph Co., San Fernando, Trinidad. |
| E. Rudland Wood | Clarence Chambers, Parliament Terrace, Harrogate. |
| G. H. Wyatt | 13 & 14, Bussey Buildings, Loveday Street, Johannesburg, Transvaal. |

ASSOCIATES.

| | |
|---|---|
| H. A. Clark | 568, Alexandra Park Road, Wood Green, N. 22. |
| N. Clough | Regent House, Kingsway, W.C. 2. |
| W. H. Derriman | Halton House, 20–23, Holborn, W.C. |
| V. H. Gregory | Lynwood, Hornsey Lane Gardens, Highgate, N. |
| C. Isaac | The New Phonopore Telephone Co., 31, Budge Row, E.C. |
| C. A. McCalla | 84, Balfour Road, Ilford. |
| C. A. Stephenson | 3, Mostyn Road, Merton, Surrey. |
| F. C. Twemlow | 132, Bury New Road, Higher Broughton, Manchester. |
| T. Webb-Watts | 67, Riversdale Road, Hawthorn, Melbourne, Australia. |

GRADUATES.

| | |
|---|---|
| D. D. Barber | c/o T. Downey, Esq., Multan Road, Lahore, India. |
| F. S. Beamish | 32, Frederick Road, Aston, Birmingham. |
| H. G. Bennett | 206, Springvale Road, Sheffield. |
| E. C. Channell | Power House, Jhelum Power Installation, Mahora, Rampur P.O., Kashmir, India. |
| A. G. Cross | 70, Brunel Terrace, Westmoreland Road, Newcastle-on-Tyne. |
| E. C. Ives | Trent, Ferozepore Road, Lahore, India. |
| L. J. Jowit | 113, Jackson Street, Stretford, Manchester. |
| A. L. Lintott | Beechlands, Chipstead, Surrey. |
| A. W. Marr | Kustore P.O., Maubhum District, Bengal, India. |
| A. J. Mavor | Caixa 63, Fortaleza, Ceara, Brazil. |
| A. K. Modi | 51, Nariman Building, Dhobitalao, Bombay, India. |
| H. A. Morris | Box 18, Koffyfontein, South Africa. |
| R. H. Nebel | 65, Mount Street, Old Charlton, Kent. |
| W. A. Welden | 71, Marlow Road, Anerley, S.E. 20. |

STUDENTS.

| | |
|---|---|
| E. C. Albrecht | 39, Beverley Crescent, Bedford. |
| A. Aldunate | Faraday House, Southampton Row, W.C. |
| Rifleman W. Baird | C Coy., 18th Reserve Battalion, London Regiment, B.E.F. |
| F. Beltran | 121, Mount Street, W. 1. |
| Petty Flight Officer O. H. D. Bennett, R.N. | R.N. Air Station, Chingford, E. 4. |
| P. S. Brett | 16, Darley Street, Gorse Hill, Manchester. |
| T. S. Brunton | c/o The Tata Hydro Electric Supply Co., Ltd., Bombay, India. |
| E. W. Cosserat | Albany House, Grosvenor Road, Rugby. |
| Lieut. F. C. Dixon | 2nd Oxford & Bucks L.I., B.E.F |
| R. C. Dunn | 38, Tavistock Square, W.C. 1 |
| W. A. H. Ellercamp | 30, Adelaide Road, S.E. 4. |
| H. A. Fichzon | The Cottage, Nursery Avenue, Hale, Cheshire. |
| J. Galveas | Caseaes, Portugal. |
| J. H. Hesketh | 10, Udney Park Road, Teddington, Middlesex. |
| H. V. Higby | 90, Oakfield Road, Selly Park, Birmingham. |
| A. H. Khan | 1213, Pollokshaws Road, Glasgow. |
| C. W. Jardine | c/o The Standard Bank of South Africa, Clement's Lane, E.C. |
| J. H. Meacock | 20, Mulgrave Road, Dollis Hill, N.W. |
| J. T. Rodwell | Canwick Vicarage, Canwick, Lincs. |
| D. E. K. Sanderson | 64, Anson Road, Tufnell Park, N. 7. |
| C. T. Scarf | 27, Khedive Road, Forest Gate, E. 7. |
| O. W. Sherwell | 9, York Place, Oxford Road, Manchester. |

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 11. February 1919. INSTITUTION NOTES. [ISSUED WITH No. 279 OF THE JOURNAL.]

## Meetings for March 1919.

### ORDINARY MEETINGS OF THE INSTITUTION.

| *Date.* 1919. | *Author and Title of Paper.* |
|---|---|
| 6 Mar. | G. L. ADDENBROOKE: Lecture on "Dielectrics." |
| 13 Mar. | G. L. ADDENBROOKE: Lecture on "Dielectrics." |
| 20 Mar. | Discussion on Mr. Addenbrooke's Lectures on "Dielectrics." |
| 21 Mar. (at 8 p.m.) | Joint Meeting and Discussion with the Royal Society of Medicine (Electrical Section) at No. 1, Wimpole-street, Cavendish-square, W. 1. |
| 27 Mar. | (To be announced later.) |

### INFORMAL MEETING.

(To be held in the rooms of the Chartered Institute of Patent Agents, Staple Inn Buildings, South Block).

| *Date.* 1919. | *Subject.* |
|---|---|
| Monday, 17 March (at 7.30 p.m.) | Discussion on "The Future of Trade Unions as affecting the Engineering Industry." (Introduced by Mr. F. POOLEY.) |

### MEETINGS OF TERRITORIAL CENTRES.

| *Date.* 1919. | *Place of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 5 Mar. | Birmingham | S. F. BARCLAY, Ph.D., and S. P. SMITH, D.Sc.: "The Determination of the Efficiency of the Turbo-Alternator." |
| 10 Mar. | Newcastle | Discussion on the President's Address to the Territorial Centres. |
| 11 Mar. | Edinburgh | Lieut.-Col. W. A. J. O'MEARA, C.M.G.: "The Functions of the Engineer: His Education and Training." |
| 11 Mar. | Leeds | H. E. YERBURY: "The Effect of Air and Water on Materials used in Engineering Work." |
| 11 Mar. | Manchester | A. G. ELLIS and J. L. THOMPSON: "Large Power Transformers." |
| 18 Mar. | Glasgow | Discussion on "Regulations for Arc Welding," and on the President's Address to the Territorial Centres. |
| 24 Mar. | Newcastle | S. F. BARCLAY, Ph.D., and S. P. SMITH, D.Sc.: "The Determination of the Efficiency of the Turbo-Alternator." |
| 25 Mar. | Manchester | Sir ERNEST RUTHERFORD, F.R.S.: Lecture on "The Atom of Electricity." |
| 26 Mar. | Birmingham | R. J. KAULA: "Notes on Surface Condensing Plants, with special reference to the requirements of large power stations." |
| 31 Mar. | Bristol | A. P. M. FLEMING, O.B.E.: "Planning a Works Research Organization." (Lecture: To be followed by a discussion.) |

### STUDENTS' SECTION.

| *Date.* 1919. | *Place and Time of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 7 Mar. | Faraday House (7 p.m.) | W. G. C. JACKSON: "The Design, Manufacture, and Operation of Transformers." |
| 18 Mar. | Finsbury Technical College (7 p.m.) | R. P. HOWGRAVE-GRAHAM: Lecture on "Oscillatory Electric Discharges"; also an exhibition of ancient and modern illuminants. |
| 28 Mar. | City and Guilds (Engineering) College, South Kensington (7 p.m.) | J. F. CROWLEY, D.Sc.: Lecture on "The Organization of Technical Engineers." |

### VISITS TO WORKS.

| *Date.* 1919. | *Time.* | *Works to be Visited.* |
|---|---|---|
| 14 Mar. | 2 p.m. | Western Electric Company, North Woolwich. |

Students who desire to take part in the above visit are requested to send in their names to the Assistant Honorary Secretary of the Students' Section, Mr. H. T. Body, 54, Chadwick-road, Leytonstone, E. 11.

## Transvaal.

The Council have appointed Mr. W. Elsdon Dew to be the Local Honorary Secretary and Treasurer of the Institution for the Transvaal in place of the late Mr. J. Hubert Davies.

## The Electrical Appointments Board.

The Electrical Appointments Board (see *Institution Notes*, No. 7, p. 26, June 1918) have on their register applications for employment from a considerable number of members of the Institution at present serving in H.M. Forces and expecting early demobilization, or recently demobilized.

The Board desire to impress upon all employers the strong claims of these members in regard to priority of employment, and they will be glad to receive particulars of vacancies in the Electrical Industry. On receipt of particulars the Board will submit to the employer the names of applicants possessing qualifications similar to those desired. No fees are charged.

Communications should be addressed to The Secretary, The Electrical Appointments Board, 1, Albemarle-street, W. 1.

The first members of the Board are :—Mr. Ll. B. Atkinson, Mr. F. Crawter, Mr. F. Gill, Mr. J. S. Highfield, Mr. H. C. Levis, Mr. W. R. Rawlings, Mr. R. T. Smith, Mr. C. P. Sparks, and Mr. J. Swinburne, F.R.S.

## Informal Meetings.

The Council have approved a scheme for holding Informal Meetings, which they hope will enable the younger members of the Institution to derive more benefit from it and to take a more active interest in its work. The meetings will be open to members of all classes and smoking will be allowed. The following Committee has been appointed to make the necessary arrangements :—

INFORMAL MEETINGS COMMITTEE.

Mr. R. Rankin (*Chairman*).

The President (*ex-officio*).

The Chairman of the Papers Committee (*ex-officio*).

| | |
|---|---|
| Mr. W. E. Bradshaw. | Mr. S. M. Hills. |
| Dr. R. D. Gifford. | Mr. F. Pooley. |
| Mr. A. F. Harmer. | Mr. W. E. Warrilow |

and three other members to be nominated later.

The first four Meetings will, by kind permission, be held in the rooms of the Chartered Institute of Patent Agents, Staple Inn Buildings (South Block), close to No. 335, High Holborn, W.C.,the subjects for discussion being as follows :

| *Date.* 1919. | *Subject.* |
|---|---|
| Monday, 17 March (7.30 p.m.) | Discussion on "The Future of Trade Unions as affecting the Engineering Industry." (Introduced by Mr. F. POOLEY.) |
| Monday, 14 April (7.30 p.m.) | Discussion on "Electrical Instruments." (Introduced by Dr. R. D. GIFFORD.) |
| Monday, 12 May (7.30 p.m.) | Discussion on "The Regulations issued by Electricity Supply Undertakings." (Introduced by Mr. W. E. BRADSHAW.) |
| Monday, 2 June (7.30 p.m.) | Discussion on "Increased Output, etc." (Introduced by MAJOR K. EDGCUMBE.) |

Arrangements are also being made for visits to Works on the afternoons of the above days (except the first). Particulars will be announced at the first Meeting.

## Wireless Sectional Meetings.

The Council have appointed the following Committee to arrange for Sectional Meetings for the reading and discussion of papers on Wireless Telegraphy.

WIRELESS SECTIONAL MEETINGS COMMITTEE.

The President (*ex-officio*).

| | |
|---|---|
| Major E. A. Barker, M.C., R.E. | Major J. Erskine-Murray, D.Sc. |
| Mr. C. Bright, F.R.S.E. | Capt. H. R. Sankey, C.B., R.E. |
| Dr. W. H. Eccles. | Mr. J. Sayers. |
| Prof. G. W. O. Howe, D.Sc. | Major T. Vincent Smith. |
| Mr. W. Judd. | Mr. A. A. Campbell Swinton, F.R.S. |
| Prof. E. W. Marchant, D.Sc. | |

Mr. J. E. Taylor

and Representatives of the Admiralty, Air Ministry, and War Office.

## Students' Section.

For the purpose of providing an effective link between the Council and the Students' Section, the Council have decided, with the concurrence of the Students' Committee, to appoint a Member of Council each year to be a consultative member of the Students' Committee. The member so appointed will only attend those meetings at which his presence is specially desired by the Committee. Mr. G. W. Partridge, Vice-President, has been appointed in this capacity by the Council for the current year.

## Paul Scholarship.

With the concurrence of Mr. R. W. Paul, whose generous gift of £500 for the development of methods and means for electrical measurements was recently recorded in the *Journal* (1919, vol. 57, p. 151), the Council have made the following arrangements :—

(*a*) The interest (about £25 per annum) on the £500 presented by Mr. Paul to be devoted to a Paul Scholarship for post-graduate work on the development of methods and means for electrical measurements.

(*b*) The Scholarship to be awarded to Students who have gone through a full electrotechnical course and have obtained a degree, diploma, or certificate equivalent to those accepted in lieu of the A.M.I.E.E. examination, on condition that they take up instrument-making work while holding the Scholarship.

(*c*) Applicants for the Scholarship to be invited to submit their names to their Professors, who will report on their applications to the following Committee which has been appointed by the Council to make the awards :—

PAUL SCHOLARSHIP COMMITTEE.

The President (*ex-officio*).

Mr. G. K. B. Elphinstone. Mr. P. Hamilton.
Mr. S. Evershed. Mr. R. W. Paul.
Mr. M. B. Field, O.B.E. Mr. A. P. Trotter
Mr. R. S. Whipple.

## Society of Radiographers.

A preliminary Committee is engaged in drawing up a draft Memorandum and Articles of Association for a proposed Society of Radiographers, whose principal objects will be to ensure that only adequately trained radiographers are employed in electro-medical work, and to promote the science and practice of Radiography. The Committee at present consists of the following :—

Mr. C. H. Wordingham, C.B.E.
Mr. J. S. Highfield.
Mr. A. A. Campbell Swinton, F.R.S. } Nominated by the Institution
Dr. R. M. Walmsley.
Dr. R. Knox.
Dr. C. R. C. Lyster.
Dr. S. Melville. } Nominated by the British Association of Radiologists and Physiotherapists
Dr. F. Hernaman-Johnson.
and the following Radiographers :
Mr. F. E. Doran, Manchester Royal Infirmary.
Mr. G. F. Westlake, Cancer Hospital, Brompton, S.W.
Mr. H. Henry, Millbank Military Hospital.
Mr. W. Turner, Middlesex Hospital.

## Conjoint Board of Scientific Societies.

The above Board have recently begun the publication of a fortnightly Bulletin containing a list of the meetings of its constituent Societies and of the papers to be read at those meetings. All communications intended for insertion in the Bulletin should be sent to Professor Gregory, 10, St. Martin's-street, W.C. 2. The price of the Bulletin is sixpence per copy.

## British Engineering Standards Association.

The Secretary of the Institution has received the following for publication :—

STANDARDIZATION OF ELECTRICAL APPARATUS.

The Sub-Committee on Electrical Accessories (under the chairmanship of Mr. C. H. Wordingham, C.B.E.) has completed the preparation of the following specifications which have just been issued by the Association :—

Electricity Meters (B.S. Report No. 37/19).
Ordinary Duty Cut-outs (B.S. Report No. 88/19).
Motor Starters (B.S. Report No. 82/19).

British Standard Specifications for the following apparatus are on the point of completion :—

(1) Instrument Transformers.
(2) Watertight Fittings.
(3) Indicating Ammeters, Voltmeters, Wattmeters, Power Factor Meters, and Frequency Meters.
(4) Recording Ammeters, Voltmeters, and Wattmeters.
(5) Heating and Cooking Apparatus.
(6) Cable Sockets and Terminals.
(7) Watertight Glands.
(8) Goliath Lampholders.

As it was found somewhat difficult to include such a wide range of subjects within the scope of a single Sub-Committee without making it unduly large, the Sectional Electrical Committee have set up the following additional Sub-Committees :—

Electricity Meters (*Chairman*, Mr. C. C. Paterson, O.B.E.).
Electrical Instruments (*Chairman*, Mr. E. B. Vignoles).
Electric Control Gear (*Chairman*, Mr. C. H. Wordingham, C.B.E.).
Heating and Cooking Apparatus (*Chairman*, Mr. S. T. Allen).

The work of the Sub-Committees on Electrical Instruments and on Heating and Cooking will not commence until the Sub-Committee on Electrical Accessories has completed the specifications now in hand.

AIRCRAFT MATERIAL.

The Association having been invited by the Department of Aircraft Production of the Ministry of Munitions to undertake the preparation of Specifications for war purposes, the Sectional Committee on Components of Aircraft and Aircraft Engines was instructed by the Main Standards Committee to take this work in hand. The Specifications issued by the Department during the past year have been prepared by this Committee and its Sub-Committees.

A Sub-Committee on Electrical Parts with Mr. C. C. Paterson, O.B.E., as Chairman, prepared a number of Specifications for electrical apparatus. The Admiralty, the Air Ministry, the Post Office, the Wireless Experimental Establishment, the National Physical Laboratory, the Society of British Aircraft Constructors, the British Electrical and Allied Manufacturers' Association, the Cable Makers' Association, and other manufacturers' Associations co-operated with the Department of Aircraft Production

on the various Panels appointed to draft the Specifications. The Specifications were issued to the Department of Aircraft Production for distribution by them to the contractors. The British Engineering Standards Association will in all likelihood continue to be the specifying body for aircraft materials in the future, the Government through the Director-General of Aircraft Production, and the makers through their recognized Association, having expressed a desire to this effect.

In view of the cessation of hostilities, the original Specifications will probably come up for revision in due course by the Electrical Section of the B.E.S.A.

The following is a list of those prepared and issued :—

B.S. Specifications for Aircraft Materials.

- E. 1. High-tension Electric Cable and Sockets.
- E. 2. Electric Supply Potential and System of Distribution.
- E. 3. Low-tension Flexible Electric Cables.
- E. 4. 6-Volt 2-Pin Polarizing Plug and Socket for Wireless Apparatus.
- E. 5. Plugs and Sockets for Electrically Heated Clothing.
- E. 6. Plugs and Sockets (3- and 4-Pin Circular Type for 12 Volts).
- E. 7. Electric Incandescent Lamps for Navigation and Recognition Lights.
- E. 8. Electric Accumulators.

## Roll of Honour.

(Twelfth List.*)

**Killed in Action.**

| | | |
|---|---|---|
| Bellamy, Lieut. H. E. | Royal Air Force | Student |
| Clears, Sapper P. J. | Royal Engineers | Associate Member |
| Gillespie, Major W. | Royal Engineers | Associate Member |
| Taylor, Lieut. A. T. | Royal Engineers | Student |
| Young, Lieut. C. | Royal Air Force | Student |

**Died of Wounds.**

| | | |
|---|---|---|
| Walker, Major R. B., M.C. | Yorkshire Hussars | Graduate |

**Drowned.**

| | | |
|---|---|---|
| Downey, Capt. W. E. | Royal Army Ordnance Corps | Associate Member |

**Died.**

| | | |
|---|---|---|
| Andrews, Lieut.-Com. H. G. | R.N.V.R. | Associate Member |
| Fisher, Sub.-Lieut. D. G. | R.N.V.R. | Student |
| French, 2nd Lieut. The Hon. E. F. | Royal Field Artillery | Associate Member |
| Linay, 2nd-Class Air Mech. R. E. | Royal Air Force | Student |
| Middleton, Staff Sergt. E. J. | London Electrical Engineers, R.E. | Associate Member |
| Orchiston, G. J. | New Zealand Expeditionary Force | Graduate |
| Whitaker, Capt. G. | Indian Army | Associate Member |

* See *Journal I.E.E.*, vol. 54, pp. 64, 447, and 675; vol. 55, pp. 55, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 7, p. 29; and No. 9, p. 4.

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 12. MARCH 1919. INSTITUTION NOTES. [ISSUED WITH No. 280 OF THE JOURNAL.]

## Meetings for April and May 1919.

ORDINARY MEETINGS OF THE INSTITUTION.

| *Date.* | *Author and Title of Paper.* |
|---|---|
| **1919.** | |
| 3 Apr. | Lieut.-Col. A. G. T. CUSINS, R.E.: Lecture on "The Development of Army Wireless during the War." |
| 10 April | R. J. KAULA: "Notes on Surface Condensing Plants, with special reference to the requirements of Large Power Stations." |
| 24 April | Major A. C. FULLER, R.E.: "The Fullerphone, and its Application to Military and Civil Telegraphy." |
| 1 May | Dr. C. CHREE, F.R.S.: Lecture on "Magnetic Storms." |
| 8 May | Joint Meeting (at 2.30 p.m.) with the Iron and Steel Institute. Papers on "Electric Furnaces." |
| 15 May | E. A. LAIDLAW and W. H. GRINSTED: "The Telephone Service of Large Cities, with special reference to London." |
| 22 May | S. CHAPMAN: "Electrical Phenomena occurring in High Atmospheric Levels." |
| 29 May | Annual General Meeting. |

INFORMAL MEETINGS.

(To be held in the rooms of the Chartered Institute of Patent Agents, Staple Inn Buildings, South Block.)

| *Date.* | *Subject.* |
|---|---|
| **1919.** | |
| Monday, 14 April (7.30 p.m.) | Discussion on "Electrical Instruments." (Introduced by Dr. R. D. GIFFORD.) |
| Monday, 12 May (7.30 p.m.) | Discussion on "The Regulations issued by Electricity Supply Undertakings." (Introduced by Mr. W. E. BRADSHAW.) |

MEETINGS OF TERRITORIAL CENTRES.

| *Date.* | *Place of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| **1919.** | | |
| 4 April | Newcastle | Annual Dinner. |
| 8 April | Glasgow | Annual General Meeting. |
| | | M. B. FIELD, O.B.E.: "The Navigational Magnetic Compass as an Instrument of Precision" (Lecture). |
| 8 April | Leeds | Dr. S. F. BARCLAY and Dr. S. P. SMITH: "The Determination of the Efficiency of the Turbo-Alternator." |
| 8 April | Manchester | Annual General Meeting. |
| 14 April | Newcastle | (To be announced later.) |
| 16 April | Birmingham | Informal Discussion on "Testing." |
| 28 April | Newcastle | Dr. J. H. PATERSON: Lecture on "Electric Welding." |
| 29 April | Sheffield | Papers on "Electric Furnaces." |
| 7 May | Birmingham | (To be announced later.) |
| 12 May | Newcastle | Annual General Meeting. |
| | | G. L. ADDENBROOKE: "Dielectrics in Electric Fields" (Lecture). |
| 13 May | Leeds | Annual General Meeting. |
| 21 May | Birmingham | (To be announced later.) |

STUDENTS' SECTION.

VISITS TO WORKS.

| *Date.* | *Time.* | *Works to be Visited.* |
|---|---|---|
| **1919.** | | |
| 9 April | 1 p.m. | Siemens Brothers and Co., Ltd., Woolwich. |
| (During May) | | Handley-Page, Ltd., Cricklewood. |

Students who desire to take part in the above visits are requested to send in their names to the Assistant Honorary Secretary of the Students' Section, Mr. H. T. Body, 54, Chadwick-road, Leytonstone, E. 11.

## Council Nominations for Election to the Council.

The following have been nominated by the Council for the vacancies which will occur in the offices of President, Vice-Presidents, Honorary Treasurer, and Ordinary Members of Council on the 30th September, 1919:—

**President.** (*One Vacancy.*)

ROGER T. SMITH.

**Vice-Presidents.** (*Two Vacancies.*)

Ll. B. Atkinson. W. B. Woodhouse.

**Honorary Treasurer.** (*One Vacancy.*)

J. Devonshire.

**Ordinary Members of Council.**

MEMBERS. (*Three Vacancies.*)

S. G. Brown, F.R.S. A. L. C. Fell.
W. H. Eccles, D.Sc. F. Gill.
S. E. Fedden. W. Judd.
B. Welbourn.

ASSOCIATE MEMBERS. (*Three Vacancies.*)

H. J. Cash. J. R. Cowie.
E. A. Gatehouse.

ASSOCIATES. (*Two Vacancies.*)

P. R. Allen. P. D. Tuckett.

## The Institution Building.

The Council have urged upon the Authorities the importance of the Institution being reinstated in its building at the earliest possible date. At the moment, H.M. Office of Works are unable to state definitely when the building will be handed back to the Institution.

## Students.

The Council have decided that, in the case of Students who have served in H.M. Forces and are not qualified for Associate Membership, the period during which they can remain in the class of Students may be extended by a period equal to the length of such service.

## Overhead Power Lines.

The Council have appointed the following Committee to consider and report on Regulations for overhead power lines, excluding tramway working conductors :—

OVERHEAD POWER LINES COMMITTEE.

The President (*ex-officio*).

| | |
|---|---|
| Mr. W. A. Chamen. | Mr. F. E. Proctor. |
| Mr J. S. Highfield. | Dr. A. Russell. |
| Mr. A. Jacob. | Mr. J. Sayers. |
| Mr. V. Page. | Mr. E. V. Twiss. |
| Mr. G. W. Partridge. | Mr. C. Vernier. |
| Mr. J. S. Peck. | Mr. B. Welbourn. |

Mr. W. B. Woodhouse.

## Benevolent Fund.

The response from members to the recent appeal for subscriptions to the above Fund has been most gratifying to the Benevolent Fund Committee. The following is a comparison of the number of subscriptions and the amounts received up to the 21st March during the present year and for the same period a year ago :—

| | Number of Subscribers | Amount Subscribed |
|---|---|---|
| **1919.** | | |
| 1 January to 21 March .. .. | 538 | £307 5s. 0d. |
| **1918.** | | |
| 1 January to 21 March .. .. | 102 | £131 14s. 0d. |

## The Divisional Engineers of the Royal Naval Division.

The following has been received from a Committee appointed by the Council to report upon the work and present position of the Divisional Engineers of the Royal Naval Division :

REPORT.

The Royal Naval Division was composed originally of the men who came forward from motives of patriotism and enthusiasm. In September 1914 the Army recruiting machinery had completely broken down, the formation of special battalions was discouraged, the Royal Engineers, the Royal Engineers (Territorial) Electrical Engineers, and other regiments were declared to be "full" with waiting lists of several hundreds. The creation of the Divisional Engineers of the Royal Naval Division opened a door for technical men, and at that time it appeared their experience in all kinds of engineering would be appreciated and utilized. It is true that if there had been less enthusiasm, and if they had waited, most of these men would have done better for themselves.

Arrangements were at once made by The Institution of Electrical Engineers, assisted by the Institutions of Civil and of Mechanical Engineers, to recruit this Unit, and the body of men sent to camp in a few days was remarkable no less for its technical ability than for its eagerness to enlist. As soon as they sailed for the Mediterranean the parent Institutions necessarily lost touch with them.

During the Gallipoli campaign the Unit was employed in such work as digging wells and building a jetty—it dwindled owing to casualties, transfers and promotions, and as there was no precedent for the Royal Naval Division, and its Divisional Engineers, there was no organization to carry on the original formation, and no source from which similar men could be drawn. The Unit had become so small by January 1917 that no other course was possible but to absorb it into the Royal Engineers.

One of the terms of the enlistment was that the Divisional Engineers would have the same standing as Royal Engineers. There was therefore no serious hardship in the absorption, except as it affected seniority, etc., though owing to the esprit de corps which had quickly developed, it was greatly to be regretted. Seniority was lost owing to the change : the men were regarded as having joined the Army at the date of transfer to the Royal Engineers, their previous services of more than two years being ignored. Seniority was restored for the officers, but possibly this has not been considered with regard to further promotion.

The employment of skilled men on unskilled work has been very common during the War, not only in the Army but in civil official work. Every man in the Unit enlisted as a sapper. The officers as well as the men were employed on unskilled work. It is true that the original contract under which they joined for three years or for the duration of the War, whichever were the shorter, was broken, and the conditions under which the men joined were not retained. But this is done under an Act which applied to men in all regiments.

That their engineering experience was but little appreciated by the military authorities is a matter beyond any control or influence that the engineering Institutions could exercise. The value of that experience and the enthusiasm of those who offered themselves is known to nobody better than to those members of the Institutions who took part in the recruiting ; and nobody can more deeply regret the waste of this fine Unit than those who are proud to have been permitted to help to form it.

The Institution of Electrical Engineers has records

of the following who enlisted in the Royal Naval Division :—

| | |
|---|---|
| Officers .. .. .. .. | 60 |
| N.C.O.'s .. .. .. .. | 10 |
| Sappers .. .. .. .. | 24 |
| Killed .. .. .. .. | 9 |
| Discharged .. .. .. | 11 |
| | 123 |

The early date of voluntary enlistment, and consequent long service, to say nothing of the disappointments which have been experienced, should weigh with the Institutions and their members in endeavouring to find appointments for men who joined as Divisional Engineers of the Royal Naval Division.

All offers of employment should be addressed to the Electrical Appointments Board, 1, Albemarle-street, W. 1.

## Roll of Honour.

(Thirteenth List.*)

**Killed in Action.**

| | | |
|---|---|---|
| Baldwin, Lieutenant H. R. | Royal Naval Division | Associate Member |
| Downes, Lieutenant H. L. | Liverpool Regt. | Associate |

**Died.**

| | | |
|---|---|---|
| Hunstone, Major W. H. | Embarkation Staff | Associate Member |
| Russell, Captain G. L. L. | Royal Engineers | Associate Member |

## Military Honours Awarded.

(Thirteenth List.†)

**C.B.**

| | | |
|---|---|---|
| Willis, Colonel R. Ff. | Royal Marine Light Infantry | Member |

**C.M.G.**

| | | |
|---|---|---|
| Evans, Lieut.-Col. Ll., D.S.O. | Royal Engineers | Associate Member |
| Knox, Lieut.-Col. G. S. | Royal Engineers | Associate Member |
| Sparks, Colonel H. C., D.S.O., M.C. | Labour Commandant | Member |

**C.B.E.**

| | | |
|---|---|---|
| Pitkeathly, Colonel J. S., C.V.O., D.S.O. | Royal Engineers | Associate Member |

**O.B.E.**

| | | |
|---|---|---|
| Alexander, Lieut.-Col. R. D. T., D.S.O. | London Regt. (attd. I.W.T.) | Associate Member |
| Balfour, Major N. H. | Royal Army Service Corps | Associate Member |
| Birch, Lieut.-Com. F. | R.N.V.R. | Associate Member |
| Campbell, Major A. S. | General List | Member |
| Carty, Major S. W., M.C. | Royal Army Service Corps | Associate Member |
| Connan, Captain J. C. | Royal Army Ordnance Corps | Associate Member |
| Cottrell, Commander W. H., C.M.G. | R.N.V.R. | Associate |
| Downie, Captain F. H. | Welsh Regt. | Associate Member |
| Edmonds, Major C. H. W. | Royal Engineers | Member |
| Geipel, Lieutenant K. S. | Royal Engineers | Associate Member |
| Laurie, Captain D. S. | Royal Engineers | Associate Member |
| Michod, Lieut.-Col. P. D. | Royal Engineers | Member |
| Robertson, Major T. E. | Royal Air Force | Associate Member |
| Wallis-Jones, Captain R. J. | Royal Field Artillery | Member |

**M.B.E.**

| | | |
|---|---|---|
| Mullard, Captain S. R. | Royal Air Force | Associate Member |
| Raven, Lieutenant N. V. | Special List | Associate Member |
| Wright, Major F. T. | Royal Army Ordnance Corps | Associate Member |

**D.S.O.**

| | | |
|---|---|---|
| Hitch, Lieut.-Col. A. T. | Bedfordshire Regt. (attd. Lincolnshire Regt.) | Student |
| Marston, Major G. S., M.C. | Royal Engineers | Associate Member |
| Webb-Bowen, Colonel H. E. | Royal Engineers | Associate Member |

**Military Cross.**

| | | |
|---|---|---|
| Ascoli, Lieutenant G. H. D. | Dragoon Guards (attd. R.E.) | Associate Member |
| Harris, Lieutenant L. G. | Manchester Regt. | Student |
| Harris, Lieutenant R. A. | Royal Engineers | Associate Member |
| Hughes, Major A. E. | Royal Engineers | Associate Member |
| Lawrence, Captain F. H. | Royal Field Artillery | Graduate |
| Macklin, Major R. W. | Royal Garrison Artillery | Associate Member |
| Madge, Major R. G. | Royal Engineers | Associate |
| O'Brien, 2nd Lieut. B. H. | Leinster Regt. | Student |
| Sargent, Major G. H. | R.A.S.C. and Tank Corps | Associate Member |
| Sawers, Captain R. | Royal Engineers | Associate Member |

* See *Journal I.E.E.*, vol. 54, pp. 64, 117, and 675; vol. 55, pp. 55, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 7, p. 29; No. 9, p. 4; and No. 11, p. 20.

† See *Journal I.E.E.*, vol. 54, pp. 306, 518, and 674; vol. 55, pp. 56, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 6, p. 24; No. 7, p. 30; and No. 9, p. 4.

**Legion d'Honneur (Croix de Chevalier).**

| | | |
|---|---|---|
| Chapple, Major F. J., D.S.O. | Royal Garrison Artillery | Associate Member |

**Croix de Guerre, avec Palme (French).**

| | | |
|---|---|---|
| Ditmas, Lieut.-Col. F. I. L., D.S.O., M.C. | Durham Light Infantry | Associate |

**Croix de Guerre (French).**

| | | |
|---|---|---|
| Chapple, Major F. J., D.S.O. | Royal Garrison Artillery | Associate Member |

**Mentioned in Despatches.**

| | | |
|---|---|---|
| Alexander, Lieut.-Col. R. D. T., D.S.O. | London Regt (attd. I.W.T.) | Associate Member |
| Allingham, Lieutenant G. C. | Royal Engineers | Associate Member |
| Baldwin, 2nd Lieut. L. C. | Royal Engineers | Associate Member |
| Balfour, Major N. H. | Royal Army Service Corps | Associate Member |
| Bamford, Lieutenant H. M. | Royal Engineers | Associate Member |
| Benning, Major B. S. | Royal Air Force | Student |
| Burford, Captain W. B. | Royal Engineers | Student |
| Chapple, Major F. J., D.S.O. | Royal Garrison Artillery | Associate Member |
| Ditmas, Lieut.-Col. F. I. L., D.S.O., M.C. | Durham Light Infantry | Associate |
| Eastman, Captain H. A. | Royal Engineers | Associate Member |
| Laurie, Captain D. S. | Royal Engineers | Associate Member |
| Lefroy, Major H. P. T., D.S.O., M.C. | Royal Engineers | Associate Member |
| Mold, Captain L. E. | Royal Engineers | Student |
| Nicholas, Captain S. W. | Royal Engineers | Associate Member |
| Pitkeathly, Colonel J. S., C.V.O., D.S.O. | Royal Engineers | Associate Member |
| Rich, Major T. | Royal Engineers | Associate Member |
| Rodwell, Major J. T. | Royal Air Force | Student |
| Sargent, Major G. H. | R.A.S.C. and Tank Corps | Associate Member |
| Trench, Major A. H. C. | Royal Engineers | Associate Member |
| Voss, Lieutenant H. A. | Royal Engineers | Graduate |

**Mentioned.**

| | | |
|---|---|---|
| Dixon, Lieutenant W. | Royal Engineers | Associate Member |
| Fraser, C.Q.M.S. A. R. | Royal Engineers | Associate Member |
| Mountain, Captain K. A. | Royal Engineers | Associate Member |
| Norman, Mech. Staff Sergt. H. | Royal Engineers | Graduate |
| Winter, Captain J. L. | Royal Engineers | Associate Member |

## Members on Military Service.

(EIGHTEENTH LIST.*)

MEMBER.

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Barnett H. T. | Royal Defence Corps | Lieutenant |

ASSOCIATE MEMBERS.

| | | |
|---|---|---|
| Bainton, L. H. | Royal Air Force | Captain |
| Catt, J. E. | R.N.V.R. | Lieutenant |
| Chamier, W. | Royal Marine Engineers | Captain |
| Croft, A. B. | Royal Engineers | Lance-Corpl. |
| Denness, T. | Royal Engineers | Captain |
| Douglas, H. M. | Royal Field Artillery | Major |
| Fell, H. H. | Royal Air Force | Lieutenant |
| Fletcher, J. R. | Royal Air Force | Sergeant |
| Forsdick, C. F. | New Zealand M.G.C. | Lieutenant |
| Gray, John | Royal Air Force | Captain |
| Hill, H. | Royal Engineers | Captain |
| Jayne, A. A., D.S.O., M.C. | Royal Engineers | Major |
| Linton, N. S. | Royal Engineers | Captain |
| Mercer, F. | Loyal North Lancashire Regt. | Lieutenant |
| Monkhouse, A. | Royal Engineers | Lieutenant |
| Morecombe, W. M. N. | Royal Engineers | 2nd Lieut. |
| Murphy, F. | Royal Air Force | Captain |
| Parry, W. | Liverpool Regt. | Private |
| Phillips, W. C. S. | Royal Air Force | Lieutenant |
| Preston, K. | Indian Army Reserve of Officers | Lieutenant |
| Quick, H. J. | Royal Navy | Electrical Engr. |
| Ransome, E. L. | Royal Air Force | Lieutenant |
| Sanders, H. E. | R.N.V.R. | Lieutenant |
| Scott, H. C. F. | Royal Engineers | Lieutenant |
| Selley, F. | Royal Air Force | Chief Petty Officer |
| Stamatopoulos, A. G. | Greek Navy | Eng.-Lieut.-Com. |
| Steele, C. H. | Royal Engineers | 2nd Lieut. |
| Whittle, H. | Royal Air Force | Sergt.-Major |

GRADUATES.

| | | |
|---|---|---|
| Barnes, L. F. | Royal Army Service Corps | Mech. Sergt.-Major |
| Collins, T. L. | Royal Air Force | 2nd Lieut. |
| Cull, E. C. | Royal Navy | Warrant Schoolmaster |
| Hunter, G. | Royal Engineers | 2nd Lieut. |
| Jacobs, E. | Royal Army Service Corps (attd. R.A.) | Private |
| Jaques, H. H. | Royal Navy | Engr. Warrant Officer |

STUDENTS.

| | | |
|---|---|---|
| Burke, J. | Royal Air Force | 1st-Class Air Mechanic |
| Dickinson, R. H. | Royal Engineers | Cadet |
| Maynard, W. M. | Royal Air Force (attd. R.G.A.) | Wireless Operator |
| Meacock, J. H. | London Rifle Brigade | Private |
| Milnes, T. | Royal Air Force | Air Mechanic |
| Reyner, J. H. | Royal Fusiliers | Lance-Corpl. |

* See *Journal I.E.E.*, vol. 53, pp. 199, 326, 388, and 857; vol. 54, pp. 121, 193, 518, and 675; vol. 55, pp. 57, 194, 326, and 538; and *Institution Notes* No. 1, p. 4; No. 4, p. 16; No. 5, p. 18; No. 7, p. 30; and No. 9, p. 4.

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 13. April 1919. INSTITUTION NOTES. [ISSUED WITH No. 281 OF THE JOURNAL.]

## Meetings for May and June, 1919.

### ORDINARY MEETINGS OF THE INSTITUTION.

[To be held, except where otherwise stated, at the Institution of Civil Engineers, Great George-street, Westminster, S.W., at 6 p.m. (light refreshments 5.30 p.m.)]

| *Date.* 1919. | *Author and Title of Paper.* |
|---|---|
| 1 May | Dr. C. Chree, F.R.S.: Lecture on "Magnetic Storms." |
| 8 May (at 2.30 p.m.) | Joint Meeting with the Iron and Steel Institute. Papers on "Electric Furnaces." |
| 14 May (Wednesday) | Major J. Erskine-Murray, R.A.F.: "Wireless in the Royal Air Force." |
| 15 May | E. A. Laidlaw and W. H. Grinsted: "The Telephone Service of Large Cities, with special reference to London." |
| 22 May | Dr. S. Chapman: "Electrical Phenomena occurring at High Levels in the Atmosphere." |
| 27 May (at 6.30 p.m.) | Joint meeting in the Lounge Hall, Caxton Hall, Westminster, S.W., with the Electrical Contractors' Association and the Association of Supervising Electricians. Discussion on "The Electrical and Engineering Equipment of Modern Small Houses" (Introduced by Mr. W. Cross). |
| 29 May (at 2.30 p.m.) | Annual General Meeting, at the Royal Society of Arts. |
| 3 June (Tuesday) | Senatore G. Marconi, G.C.V.O., LL.D., D.Sc.: "The Continuous-wave Plant at the Carnarvon Station." |

### INFORMAL MEETINGS.

(To be held in the rooms of the Chartered Institute of Patent Agents, Staple Inn Buildings, South Block, at 7.30 p.m.)

| *Date.* 1919. | |
|---|---|
| 12 May | Discussion on "The Regulations issued by Electricity Supply Undertakings" (Introduced by Mr. W. E. Bradshaw). |
| 2 June | Discussion on "The Vicious Circle of Increasing Prices" (Introduced by Major K. Edgcumbe). |

### MEETINGS OF TERRITORIAL CENTRES.

| *Date.* 1919. | *Place of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 1 May | Middlesbrough | Dr. J. H. Paterson: Lecture on "Electric Welding," followed by a discussion on "Regulations for Electric Arc Welding." |
| 7 May | Birmingham | Papers on "Electric Furnaces." |
| 12 May | Newcastle | Annual General Meeting. G. L. Addenbrooke: Lecture on "Dielectrics in Electric Fields." |
| 13 May | Leeds | Annual General Meeting. |
| 21 May | Birmingham | Annual General Meeting. G. L. Addenbrooke: Lecture on "Dielectrics in Electric Fields." |

### STUDENTS' SECTION.

| *Date.* 1919. | *Place of Meeting.* | *Author and Title of Paper.* |
|---|---|---|
| 9 May | Finsbury Technical College (7 p.m.) | C. E. Webb: "The Principles of Scientific Illumination." |
| 23 May | City and Guilds (Engineering) College (7 p.m.) | W. J. Jones: "Methods of Rectifying Alternating Currents, and their Application." |
| June | Informal Dinner. | |

### VISIT TO WORKS.

| *Date.* 1919. | *Works to be Visited.* |
|---|---|
| 21 May | L.B. and S.C. Railway. |
| (During June) | Handley-Page, Ltd., Cricklewood. |

Students who desire to take part in the above visits are requested to send in their names to the Assistant Honorary Secretary of the Students' Section, Mr. H. T. Body, 54 Chadwick-road, Leytonstone, E. 11.

## Annual General Meeting, 29 May, 1919.

The Annual General Meeting of the Institution (Members, Associate Members, and Associates only) will be held at the Royal Society of Arts, John-street, Adelphi, W.C., on Thursday, 29th May, 1919, at 2.30 p.m., to receive and consider the Annual Report of the Council and the Accounts for the year ended 31st December, 1918, and to elect Auditors.

The Report and Accounts will be found on pages 322 and 332 of the present Number of the *Journal* (No. 281).

## Students' Section.

Arrangements are being made for an informal dinner of the Students' Section early in June. The dinner will be followed by a musical programme.

Offers of assistance in the musical programme will be welcomed by the Dinner Sub-Committee and should be sent as soon as possible to Mr. H. T. Body, 54 Chadwick-road, Leytonstone, E. 11.

## Irish Centre.

Mr. R. Tanham has been appointed Chairman of the Irish Centre for the remainder of the present session, in place of the late Mr. J. P. Tierney.

## Territorial Sub-Centres.

In view of the success of the Tees-side Sub-Centre a Territorial Sub-Centre has been established at Sheffield, and others will shortly be established at Aberdeen, Leicester, and Preston, for the purpose of holding local informal meetings at regular intervals, in addition to holding each session at the Sub-Centre one or two meetings of the parent Centre.

## Wireless Sectional Meetings.

The complete list of members of the Wireless Sectional Meetings Committee is as follows :—

Dr. W. H. Eccles (*Chairman*).

The President (*ex-officio*).

The Chairman of the Papers Committee (*ex-officio*).

Major E. A. Barker, M.C., R.E.
Mr. Charles Bright, F.R.S.E.
Professor G. W. O. Howe.
Admiral Sir H. B. Jackson, F.R.S.
Mr. W. Judd.
Sir Oliver Lodge, O.M., F.R.S.
Prof. E. W. Marchant.
Dr. G. Marconi, G.C.V.O.
Major J. Erskine-Murray, R.A.F.
Mr. J. Sayers.
Major T. Vincent Smith, R.A.F.
Mr. A. A. C. Swinton, F.R.S.
Mr. J. E. Taylor,

and

Captain J. K. Im Thurn, R.N. (nominated by the Admiralty).
Lt.-Col. A. D. Warrington-Morris, O.B.E., R.A.F. (nominated by the Air Ministry).
Lt.-Col. W. Ll. Evans, C.M.G., D.S.O., R.E. (nominated by the War Office).
Mr. E. H. Shaughnessy, O.B.E. (nominated by the Post Office).

Arrangements have been made for the following further meetings during the present session :—

Wednesday, 14 May :—Major J. Erskine-Murray : " Wireless in the Royal Air Force."
Tuesday, 3 June :—Senatore G. Marconi, G.C.V.O., LL.D., D.Sc. : " The Continuous-wave Plant at the Carnarvon Station."
(Date to be fixed) :—Captain L. B. Turner, M.A. : " The Oscillatory Valve Relay : a Thermionic Trigger Device."

## Overhead Power Lines.

Mr. S. C. Bartholomew and Mr. A. P. Trotter have been appointed by the Council to be members of the Overhead Power Lines Committee (see *Institution Notes*, No. 12, page 22, March 1919).

## British Standards for Annealed Copper Conductors.

A copy of the above publication of the British Engineering Standards Association is enclosed with this issue of the *Journal*.

## Informal Meetings.

The first Informal Meeting was held on Monday, 17th March, 1919, at 7.30 p.m., at the Chartered Institute of Patent Agents, Staple Inn Buildings, W.C.

The Chair was taken by Mr. C. H. Wordingham, C.B.E. (President), during the earlier part and by Mr. R. Rankin during the remainder of the meeting.

After an opening statement by Mr. Wordingham on the objects of the Meetings, Mr. F. Pooley opened a discussion on " The Future of Trade Unions as affecting the Engineering Industry," and in the discussion which followed, Messrs. R. Rankin, R. W. Paul, R. W. Law, R. E. Dickinson, Dr. R. D. Gifford, and Mr. W. J. Oswald spoke.

At the second Informal Meeting, which was held on Monday, 14th April, 1919, Mr. R. Rankin in the chair, Dr. R. D. Gifford opened a discussion on " Electrical Instruments," in which the following took part : The Chairman, Messrs. A. W. Marshall, R. W. Paul, Lieut. J. A. B. Horsley, R.N.V.R., Mr. A. F. Harmer, Lieut. C. G. Rattray, R.N.V.R., Messrs. Kenelm Edgcumbe, D. A. Christian, R. W. Law, S. A. Laird, and Leslie Miller.

## Promotions, Transfers, etc., of Members on Military Service.

(Fourteenth List.*)

Members.

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Anderson, J. A. | Royal Engineers | Major |
| Barker, E. A., M.C. | Royal Engineers | Major |
| Capper, D .S. | Officers Training Corps | Lieut.-Col. |
| Cormack, J. D., C.M.G., C.B.E. | Special List | Brig.-Gen. |
| Crawley, C. G. G. | Royal Marines | Lieut.-Col. |

* See *Journal I.E.E.*, vol. 54, pp. 307, 404, 579, and 675 ; vol. 55, pp. 59, 95, 327, and 539 ; and *Institution Notes*, No. 2, p. 8 ; No. 3, p. 11 ; No. 5, p. 19 ; No. 7, p. 30 ; and No. 9, p. 5.

MEMBERS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Dashwood, E. S. | Royal Marine Artillery | Captain |
| Hooghwinkel, G. H. J. | Royal Field Artillery | Major |
| Nicholson, J. S. | Royal Air Force | Major |
| Salt, C. W. | Royal Engineers | Captain |
| Saunders, E. S. | Royal Air Force | Major |
| Williams, C. T. | Royal Engineers | Major |
| Wimperis, H. E. | Royal Air Force | Major |

ASSOCIATE MEMBERS.

| | | |
|---|---|---|
| Aldous, F. C. | Machine Gun Corps | Lieut.-Col. |
| Amberton, R. | General List | Major |
| Arnold, C. L. | Royal Garrison Artillery | Captain |
| Atkinson, A. M. | Royal Engineers | Captain |
| Bamford, H. M. | Royal Engineers | Captain |
| Barnard, J. | Royal Army Ordnance Corps | Captain |
| Belfield, S. C. | Royal Air Force | Major |
| Bellman, H. | Royal Engineers | Lieutenant |
| Bennett, E. J. L. | Royal Field Artillery | Major |
| Bland, R. W. H. M. | Labour Corps | Captain |
| Bodkin, G. S. C. | Royal Engineers | Lieutenant |
| Boyd, W. B. | Royal Field Artillery | Lieutenant |
| Brandreth, F. H. | Essex Regt. | Captain |
| Brotherton, C. E. | Royal Engineers | Lieutenant |
| Bullard, F. R. | Derbyshire Yeomanry (att. R.E.) | Lieutenant |
| Burns, S. | General List | Lieutenant |
| Caparn, E. T., M.C. | Royal Engineers | Major |
| Carver, W. M. | Special List | Captain |
| Casperd, C. C. | R.N.V.R. | Lieutenant |
| Cheal, A. E. E. | General List | Captain |
| Clayton, A. E. | London Electrical Engineers, R.E. | Staff Sergt. |
| Clayton, B. C. | Royal Air Force | Major |
| Cockshott, E. H. | Royal Air Force | Captain |
| Curling, H. W., M.C. | Royal Army Service Corps | Major |
| Dickinson, A. J. | Royal Engineers | Lieut.-Col. |
| Donkersley, N. | Royal Engineers | Sapper |
| Eastman, H. A. | Royal Engineers | Actg. Capt. |
| Edward, W. G. | Royal Engineers | Captain |
| Ferguson, J. | Royal Engineers | Lieutenant |
| Fraser, P. L. R. | Royal Air Force | Captain |
| Friend, R. H. | Royal Engineers | Lieutenant |
| Geipel, K. S. | Royal Engineers | Lieutenant |
| Geoghegan, F. W. | R.N.V.R. | Lieut.-Com. |
| Goodall, F. H. | Royal Engineers | Captain |
| Goulden, C. H., M.C. | Royal Engineers | Captain |
| Graves, E. | Indian Army Reserve of Officers | Captain |
| Grice, P. | North Staffordshire Regt. (att. R.E.) | Captain |
| Griggs, J. W. | Royal Air Force | Major |
| Gundry, W. L. D. | Royal Engineers | Lieutenant |
| Hart, W. H. | Royal Army Service Corps | Captain |
| Hay, P. G. | Royal Engineers | Lieutenant |
| Horner, F. H. | Royal Engineers | Lieutenant |
| Iles, F. A., D.S.O. | Royal Engineers | Colonel |
| Jacques, G. | Royal Air Force | Major |
| Kapp, R. O. | Royal Engineers | 2nd Lieut. |
| Kirkby, H. M., M.C. | Royal Army Ordnance Corps | Lieut.-Col. |
| Klitz, R. W. | Royal Army Ordnance Corps | Captain |

ASSOCIATE MEMBERS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Lawson, F. A. | Cheshire Regt. | Lieutenant |
| Lincoln, J. W., M.C. | Royal Engineers | Lieut.-Col. |
| Linsley, D. H. | Royal Army Ordnance Corps | Arm. Staff Sergt. |
| Linton, N. S. | Royal Engineers | Major |
| Lion, B. S. | Royal Engineers | Captain |
| Lovell, W. H., M.C. | Grenadier Guards | Captain |
| Macklin, R. W., M.C. | Royal Garrison Artillery | Major |
| Malden, C. H. | Royal Marine Light Infantry | Major |
| Mason, H. F. | Royal Garrison Artillery | Major |
| Matravers, F. G. | Royal Navy | Eng.-Lieut.-Com. |
| McNaughton, A. G. L., D.S.O. | Canadian Field Artillery | Brig.-Gen. |
| Miller, J. A. | Royal Engineers | Lieutenant |
| Miller, N. | Royal Army Service Corps | Captain |
| Moore, T. | Royal Air Force | Captain |
| Murray, G. | Indian Army Reserve of Officers | Actg. Capt. |
| Mulliner, A. M. | Royal West Surrey Regt. | Lieutenant |
| Nimmo, H. | Royal Engineers | Captain |
| Outram, H. W. S. | Royal Air Force | Lieut.-Col. |
| Overton, T. R. | New Zealand Engineers | Lieutenant |
| Parker, C. E. F. | Monmouthshire Regt. | Lieutenant |
| Pate, W. | Royal Marines | Captain |
| Pearson, R. L. | Berkshire Yeomanry | Major |
| Peel, M. L. | Cape Fortress Engineers | Staff Sergt.-Maj. |
| Peter, L. H., M.C. | Royal Air Force | Major |
| Philipp, R. C., M.C. | Royal Engineers | Captain |
| Pitt, P. S. | Royal Army Service Corps | Captain |
| Pope, W. G. T., M.C. | Royal Engineers | Major |
| Potts, T. F. | Royal Engineers | Qmr.-Sergt. |
| Pratt, L. H. | Royal Engineers | Lieutenant |
| Prendergast, H. H. L. | Royal Engineers | Captain |
| Pudan, T. A. | Royal Air Force | Sergeant |
| Puttick, A. W., M.C. | Hampshire Regt. | Lieut.-Col. |
| Rudd, S. | Royal Garrison Artillery | Lieutenant |
| Sanders, H. E. | R.N.V.R. | Lieut.-Com. |
| Sandford, P. P. | Royal Army Service Corps | Captain |
| Saner, E. J. | Special List | Captain |
| Sargent, G. H., M.C. | Tank Corps | Lieut.-Col. |
| Searle, A. M. | Royal Engineers | Captain |
| Short, E. A. | Royal Engineers | Major |
| Sizer, N., M.C. | Royal Engineers | Captain |
| Staniar, H. D. | Royal Air Force | Captain |
| Stone, A. A. | Royal Army Service Corps | Lieutenant |
| Summers, L. F. | Royal Army Service Corps | Captain |
| Sutcliffe, W. | Royal Army Service Corps | Major |
| Thomas, J. H. | Royal Engineers | Captain |
| Tomlinson, N. B. | Royal Air Force | Major |
| Tuppen, H. R., M.C. | Royal Army Service Corps | Major |
| Utting, S. | Royal Army Service Corps | Major |
| Vincent, J. D. A. | Leicestershire Regt. | Major |
| Wade, C. | Royal Army Service Corps | Captain |
| Webb, H. J. G. | Royal Engineers | Captain |
| Webbe, D. B. | Royal Engineers | 2nd Lieut. |

ASSOCIATE MEMBERS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Wenger, T. L., M.C. | Tank Corps | Major |
| Wilmot, A. C. | Staff for R.E. Services | Captain |
| Wood, E. L. | Tank Corps | Major |
| Wythes, F. V. | Royal Engineers | Lieutenant |

ASSOCIATES.

| | | |
|---|---|---|
| Chaster, C. S. | Royal Engineers | 2nd Lieut. |
| Clark, R. C. G. | Lancashire Fusiliers | Major |
| Grigg, R. | Royal Engineers | Captain |
| Foinette, T. W. | Royal Army Ordnance Corps | Lieutenant |
| Hunter, W. H., M.C. | Royal Army Service Corps | Major |
| Madge, R. G., M.C. | Royal Engineers | Major |
| Quennell, W. A. | Royal Army Ordnance Corps | Major |
| Tucker, W. S. | Royal Engineers | Major |
| Webber, W. J. | Royal Air Force | Lieutenant |

GRADUATES.

| | | |
|---|---|---|
| Bailey, A. | Royal Engineers | Captain |
| Chandler, C. K. | Royal Air Force | Captain |
| Glass, C. G. | Machine Gun Corps | Lieutenant |
| Harriss, G. S. | Royal Engineers | Captain |
| Jones, E. F., M.C. | Royal Field Artillery | Major |
| McLean, W. A. G. | Indian Army Reserve of Officers | 2nd Lieut. |
| Preston, E. B. | Royal Engineers | Lieutenant |
| Shaw, W. J. | Royal Army Service Corps | Captain |
| Smiles, C. A. | R.N.V.R. | Lieutenant |
| Soper, V. | Dorsetshire Regt. and R.A.F. | Lieutenant |

STUDENTS.

| | | |
|---|---|---|
| Armstrong, H. | Royal Army Service Corps | Lieutenant |
| Budgen, H. P. | R.N.V.R. | Sub-Lieut. |
| Charnley, J. H. | Royal Engineers | Lieutenant |

STUDENTS—*continued.*

| *Name.* | *Corps, etc.* | *Rank.* |
|---|---|---|
| Cheel, E. S., M.C. | Royal West Kent Regt. | Lieutenant |
| Collard, J. | Suffolk Regt. | Private |
| Cuerden, H. S. | Royal Army Service Corps | Lieutenant |
| Dawes, R. R. | Royal Engineers | 2nd Lieut. |
| Denison, H. A., M.C. | King's Royal Rifle Corps | Major |
| Dobie, P. | Royal Scots Fusiliers | Lieutenant |
| Dunham, D. | South Lancashire Regt. (attd. R.E.) | Lieutenant |
| Edminson, E. | Tank Corps | 2nd Lieut. |
| England, M. O. F. | Royal Air Force | Captain |
| Gibbard, H. E. | Royal Engineers | 2nd Lieut. |
| Headwards, H. H. | Royal Engineers | Lieutenant |
| Hitch, A. T., D.S.O. | Bedfordshire Regt. | Lieut.-Col. |
| Jones, L. J. | Royal Air Force | Corporal |
| King, L. S. | Royal Engineers | Lieutenant |
| Knight, J. M. | King's Royal Rifle Corps | Lieutenant |
| Lee, H. J. | Royal Engineers | Sergeant |
| Lovegrove, C. G. | Royal Garrison Artillery | Lieutenant |
| McNaught, R. M. | Royal Engineers | Lieutenant |
| Perrow, F. A. P. | South African Medical Corps | Captain |
| Powell, C. A. W. | Royal Engineers | Captain |
| Pritt, S. E. | Royal Engineers | Corporal |
| Riley, T. S., M.C. | Royal Army Service Corps | Lieutenant |
| Rowles, A. H. | Royal Engineers | Lieutenant |
| Ryder, P. G. | Royal Army Service Corps | Lieutenant |
| Simkiss, E. | South Staffordshire Regt. | Lieutenant |
| Smith, L. C. R., M.C. | Royal West Kent Regt. | Major |
| Vowell, C. | New Zealand Signal Section | Sapper |
| Winn, J. G. W. | Royal Engineers | Lieutenant |
| Workman, E. W. | Labour Corps | Lieutenant |
| Young, R. | South Lancashire Regt. | Lieutenant |

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 14. May 1919. INSTITUTION NOTES. [ISSUED WITH No. 282 OF THE JOURNAL.]

## Forthcoming Meetings, etc.

ORDINARY MEETING.

[To be held at the Institution of Civil Engineers, Great George-street, Westminster, S.W., at 6 p.m. (light refreshments, 5.30 p.m.).]

1919.
30 June (Monday) Captain L. B. Turner, M.A.: "The Oscillatory Valve Relay: a Thermionic Trigger Device" (with demonstrations).

CONVERSAZIONE AND ANNUAL DINNER.

1919.
25 June (at 8 p.m.) Conversazione at the Natural History Museum, South Kensington.
26 June (at 7 for 7·30 p.m.). Annual Dinner, at the Connaught Rooms, Great Queen-street, W.C.

STUDENTS' SECTION.

1919.
5 July 2 p.m. Visit to National Physical Laboratory, Teddington.

Students who desire to take part in the above visit are requested to apply for tickets of admission as soon as possible to the Assistant Honorary Secretary of the Students' Section, Mr. H. T. Body, 54 Chadwick-road, Leytonstone, E. 11. Admission will be by ticket only.

## Annual Conversazione.

By permission of the trustees of the Natural History Museum, a conversazione, to meet the members of the Institution who have served in H.M. Forces during the War, will be held at the Museum, Cromwell Road, S.W., on Wednesday, 25th June, from 8 p.m. to 11 p.m. Invitations have been sent to all members and an early reply to the Secretary is requested.

## Annual Dinner.

The Annual Dinner of the Institution will be held at the Connaught Rooms, Great Queen-street, London, W.C. 2, on Thursday, 26th June, at 7 p.m. for 7.30 p.m. Members who wish to be present are requested to make early application to the Secretary for tickets.

## North-Western Centre.

Mr. A. G. Ellis has been elected Honorary Secretary of the above Centre in place of Mr. J. Frith, who has resigned after holding office for seven years.

## Council for the Year 1919-20.

The result of the ballot for the vacancies which will occur in the offices of President, Vice-President, Honorary Treasurer, and Ordinary Members of Council on the 30th September, 1919, was reported at the Ordinary Meeting on the 22nd May to be:—

*President:* Roger T. Smith.
*Vice-Presidents:* L. B. Atkinson and W. B. Woodhouse.
*Honorary Treasurer:* J. Devonshire.
*Ordinary Members of Council:* (*Members*) Dr. W. H. Eccles, S. E. Fedden, and B. Welbourn; (*Associate Members*) H. J. Cash, J. R. Cowie, and E. A. Gatehouse; (*Associates*) P. R. Allen and P. D. Tuckett.

The Council for the year 1919-20 will therefore be constituted as follows:—

### President.

Roger T. Smith.

### The Past-Presidents.

### Vice-Presidents.

L. B. Atkinson.
W. A. Chamen.
G. W. Partridge.
W. B. Woodhouse.

### Honorary Treasurer.

J. Devonshire.

### Ordinary Members of Council.

P. R. Allen.
H. J. Cash.
H. W. Clothier.
J. R. Cowie.
D. N. Dunlop.
Dr. W. H. Eccles.
S. E. Fedden.
E. A. Gatehouse.
Sir R. A. Hadfield, Bart., F.R.S.
J. S. Highfield.
Prof. E. W. Marchant, D.Sc.
C. C. Paterson, O.B.E.
J. Sayers.
Sir W. Slingo.
Col. H. C. Sparks, C.M.G., D.S.O., M.C.
A. P. Trotter.
P. D. Tuckett.
B. Welbourn.

and

The Chairman and Immediate Past-Chairman of each Territorial Centre.

## List of Members.

A new edition of the list of members of the Institution is in preparation. In view of the high cost of printing and paper only a limited number of copies will be printed, and members wishing to receive copies are requested to make early application to the Secretary. Copies will be ready for despatch in August or September.

## Societé des Ingenieurs-Civils de France.

A British Section of the Société des Ingenieurs-Civils de France has been formed in London under the direct authority of the parent Society. The provisional Council and Officers include Mr. C. H. Wordingham, C.B.E., Hon. President; Mr. T. J. Gueritte, Acting-President; the Marquis de Chasseloup-Laubat, Delegate of the Parent Society; Messrs. W. R. Howard, M. E. de Jarny, A. Jouve, H. Sloog, and W. Noble Twelvetrees, Members of Council; and H. Sloog, Hon. General Secretary. It is proposed to hold meetings in London, to provide facilities for social intercourse between members of the Section and their friends, and to make arrangements with the object of keeping the French Society in touch with the principal British Engineering Institutions.

## Library and Museum.

Mr. J. J. Fahie has kindly presented to the Institution Library and Museum a collection of papers, letters, MSS., etc., of electrical interest from about 1865 to 1918, and a number of engravings and photographs of old telegraph apparatus.

## Lending Library.

In order to meet the demands for technical literature from members serving in the Army of Occupation on the Rhine, books may now be borrowed from the Lending Library by members serving in this Army.

In order to cover the period of transit through the post, 28 days instead of 14 will be allowed for the retention of a book, and with this exception the existing rules of the Lending Library will apply.

## Informal Meeting.

The third Informal Meeting was held on Monday, 12th May, 1919, at 7.30 p.m., at the Chartered Institute of Patent Agents, Staple Inn Buildings, W.C., Mr. F. Pooley in the chair.

Mr. W. E. Bradshaw opened a discussion on "The Regulations issued by Electricity Supply Undertakings," in which the following took part: Messrs. F. Pooley, C. A. Baker, E. S. Ritter, A. G. Hilling, R. Grierson, R. W. Law, W. A. Brown, A. F. Harmer, W. L. Wreford, H. Bentham, and H. L. Leach.

## Joint Meeting.

A Joint Meeting of members of the Institution, the Electrical Contractors' Association, and the Association of Supervising Electricians was held on Tuesday, 27th May, 1919, at 6.30 p.m., at Caxton Hall, Westminster. The chair was taken by Mr. C. H. Wordingham, C.B.E. (President of the Institution), during the earlier part and by Mr. H. J. Cash (President of the Electrical Contractors' Association) during the remainder of the meeting.

After an explanatory statement by Mr. Wordingham in regard to the objects of the Meeting, Mr. W. Cross opened a discussion on "The Electrical and Engineering Equipment of Modern Small Houses." In the discussion which followed, Messrs. J. S. Highfield, W. R. Rawlings, H. W. Pinkney, W. J. Revell, L. Milne, A. Broadway, F. W. Marshall, A. J. Stiling, C. F. Proctor, J. M. Crowdy, W. Ellerd-Styles, A. P. Trotter, A. Shearman, F. C. Raphael, R. Whitley, and H. J. Cash took part.

## Military Honours Awarded.

(Fourteenth List.*)

| | | |
|---|---|---|
| **C.B.** | | |
| Brown, Brig.-Gen. W. B. | Royal Engineers | Member |
| Gardiner, Lieut.-Col. B. C. | Royal Marine Light Infantry | Member |
| **C.M.G.** | | |
| Lister, Lieut.-Col. J. F. | Royal Engineers | Member |
| **C.B.E.** | | |
| Cormack, Brig.-Gen. J. D., C.M.G. | Special List | Member |
| **O.B.E.** | | |
| Binyon, Major B. | Royal Air Force | Associate Member |
| Bowden, Lieut.-Col. J. | Royal Engineers | Associate Member |
| Hunn, Lieutenant J. A. | R.N.V.R. | Associate Member |

* See *Journal I.E.E.*, vol. 54, pp. 306, 513, and 674; vol. 55, pp. 56, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 6, p. 24; No. 7, p. 30; No. 9, p. 4; and No. 12, p. 23.

| | | |
|---|---|---|
| Jayne, Major A. A., D.S.O., M.C | Royal Engineers | Associate Member |
| Judson, Lieut.-Col. D., J.P. | Special List | Member |
| Long, Major S. H. | Royal Engineers | Associate Member |
| Nicholas, Captain S. W. | Royal Engineers | Associate Member |
| Wray, Commander T. H. R. | R.N.V.R. | Associate Member |

**D.S.O.**

| | | |
|---|---|---|
| Angwin, Major A. S., M.C. | Royal Engineers | Associate Member |
| Groom, Captain H. R. L., M.C. | Royal Engineers | Associate Member |

**M.B.E.**

| | | |
|---|---|---|
| Bayley, Captain B. C. | Royal Engineers | Associate Member |
| Hutt, Captain A. | Special List | Associate Member |
| Nicholson, Captain J. S. | Royal Air Force | Member |

**Bar to Military Cross.**

| | | |
|---|---|---|
| Massie, Lieut.-Col. I. W., M.C. | Royal Engineers | Associate Member |

**Military Cross.**

| | | |
|---|---|---|
| Aylmer, Captain J. | Royal Fusiliers | Student |
| Church, 2nd Lieut. H. | Royal Engineers | Associate Member |
| Corbac. Lieutenant G. H. van | Canadian Infantry | Member |
| Foster, Major F. W. | Leicestershire Regt. | Associate Member |
| Roberts, Major W. | Royal Field Artillery | Associate Member |
| Wolf, Captain E. M. | Tank Corps | Graduate |

**Air Force Cross.**

| | | |
|---|---|---|
| Peter, Major L. H., M.C. | Royal Air Force | Associate Member |

**Ordre de la Couronne, Chevalier.**

| | | |
|---|---|---|
| Turner, Captain H. E. | Royal Garrison Artillery | Associate Member |

**Croix de Guerre (Belgium).**

| | | |
|---|---|---|
| Turner, Captain H. E. | Royal Garrison Artillery | Associate Member |

**Cruz de Guerra (Portugal).**

| | | |
|---|---|---|
| Williams, Lieutenant C. S., M.C. | Royal Engineers | Student |

**Mentioned in Despatches.**

| | | |
|---|---|---|
| Alkin, Captain R. L. | Royal Engineers | Member |
| Carty, Major S. W., M.C. | Royal Army Service Corps | Associate Member |
| Cottrell, Commander W. H., C.M.G., O.B.E. | R.N.V.R. | Associate |
| Saltren-Willett, Colonel A. J. | Royal Artillery | Associate |
| Skinner, Sergeant C. W. | Honourable Artillery Company | Institution Staff |
| Taylor, Commander H. B. | Royal Navy | Associate Member |
| Ward, Lieutenant E. J. | Royal Irish Regt. | Associate Member |

**Mentioned.**

| | | |
|---|---|---|
| Barker, Major E. A., M.C. | Royal Engineers | Member |
| Clarke, Captain J. | Royal Engineers | Member |
| Corbett, Lieutenant R. W. T. | Royal Engineers | Associate Member |
| Goodall, Captain F. H. | Royal Engineers | Associate Member |
| Henrici, Major E. O. | Royal Engineers | Associate Member |
| Masters, Captain F. H. | Royal Engineers | Associate Member |
| Nimmo, Lieutenant H. | Royal Engineers | Associate Member |
| Sadd, Captain J. A. | Royal Engineers | Associate Member |
| Tyler, Colonel H. E. | Royal Engineers | Associate |
| Woodward, Captain E. H. E., M.C. | Royal Engineers | Associate Member |

## Accessions to the Lending Library.

ANDERSON, J. Electric locking.
8vo. 219 pp. *New York*, [1918]

BALL, W. V. The law affecting engineers.
8vo. 332 pp. *London*, 1906

BATESON, W. Municipal office organization and management. Edited by W.B., with contributions by experienced authorities on municipal work and practice. 1a. 8vo. 502 pp. *London, n.d.*

BLAKE, H. W., and JACKSON, W. Electric railway transportation. 8vo. 494 pp. *New York*, 1917

BROWN, H. W. Electrical equipment. Its selection and arrangement; with special reference to factories, shops, and industrial plants.
8vo. 242 pp. *New York*, 1917

BUCHER, E. E. Practical wireless telegraphy. A complete text book for students of radio communication. Revised ed.
8vo. 344 pp. *New York*, 1918

BURTON, F. G. The commercial management of engineering works. 2nd ed.
8vo. 447 pp. *Manchester*, 1905

—— Engineering estimates and cost accounts. 2nd ed. sm. 8vo. 142 pp. *Manchester*, 1906

CARTER, R. N. Advanced accounts. A manual of advanced book-keeping and accountancy for accountants, book-keepers, and business men. Edited by R.N.C. 8vo. 988 pp. *London, n.d.*

COLES, A. Company accounts. With a Preface by C. Comins. 2nd ed., with especial reference to liquidation accounts. 8vo. 356 pp. *London, n.d.*

COMSTOCK, D. F., and TROLAND, L. T. The nature of matter and electricity. 2nd printing.
8vo. 225 pp. *New York*, 1910

CROFT, T. Electrical machinery. Principles, operation and management. 8vo. 328 pp. *New York*, 1917

CROFT, T. Practical electric illumination. 8vo. 236 pp. *New York*, 1917

—— Practical electricity. 8vo. 660 pp. *New York*, 1917

DOVER, A. T. Electric motors and control systems: a treatise on electric traction motors and their control. 8vo. 388 pp. *London*, 1918

—— Electric traction. 8vo. 686 pp. *London*, 1917

—— Power wiring diagrams. A handbook of connection diagrams of control and protective systems for industrial plants. sm. 8vo. 223 pp. [*London*, 1917]

DUDENEY, F. M. The exporter's handbook and glossary. With a foreword by W. Eglington. 8vo. 253 pp. *London*, [1916]

ECCLES, W. H. Wireless telegraphy and telephony. A handbook of formulæ, data and information. 2nd ed. 8vo. 519 pp. *London*, 1918

EDGCUMBE, K. Industrial electrical measuring instruments. 2nd ed. 8vo. 430 pp. *London*, 1918

EKE, J. A. The elements of insurance. sm. 8vo. 140 pp. *London, n.d.*

GANDY, J. P. The elements of banking. sm. 8vo. 140 pp. *London, n.d.*

GOLDSMITH, A. N. Radio-telephony. 8vo. 252 pp. *New York*, [1918]

GRIERSON, R. Some modern methods of ventilation. 8vo. 201 pp. *London*, 1916

HALE, A. J. The applications of electrolysis in chemical industry. 8vo. 157 pp. *London*, 1918

HAMILTON, D. T., and OBERG, E. Electric welding. 8vo. 302 pp. *New York*, 1918

HAWKINS, C. C., SMITH, S. P., and NEVILLE, S. Papers on the design of alternating current machinery. 8vo. 407 pp. *London*, 1919

HEELIS, F. Theory and practice of commerce. Edited by F. H., assisted by specialist contributors. 8vo. 594 pp. *London, n.d.*

HERING, C., and GETMAN, F. H. Standard table of electrochemical equivalents and their derivatives, with explanatory text, etc. sm. 8vo. 140 pp. *New York*, 1917

HOBART, H. M. The electric propulsion of ships. 8vo. 179 pp. *London*, 1911

JOHNSON, J. B. Engineering contracts and specifications. 3rd ed. 8vo. 581 pp. *New York*, 1904

KEMP, P. Alternating current electrical engineering. 8vo. 505 pp. *London*, 1918

KENNELLY, A. E. Artificial electric lines, their theory, mode of construction and uses. 8vo. 355 pp. *New York*, 1917

KLINGENBERG, G. Large electric power stations. Their design and construction. English transl. la. 8vo. 276 pp. *London*, 1916

LEAKE, P. D. Depreciation and wasting assets. [2nd ed.] 8vo. 257 pp. *London*, 1917

LIVENS, G. H. The theory of electricity. la. 8vo. 723 pp. *Cambridge*, 1918

LYNDON, L. Hydro-electric power. 2 vol. 8vo. *New York*, 1916

1. Hydraulic development and equipment.
2. Electrical equipment and transmission.

MALCOLM, H. W. The theory of the submarine telegraph and telephone cable. 8vo. 576 pp. *London*, 1917

MARTIN, M. J. Wireless transmission of photographs. 8vo. 128 pp. *London*, 1916

MAY, I. A. Street railway accounting. A manual of operating practice for electric railways. 8vo. 474 pp. *New York*, 1917

MAYCOCK, W. P. A small book on electric motors for continuous and alternating currents. 8vo. 212 pp. *London*, 1918

MILLIKAN, R. A. The electron. Its isolation and measurement and the determination of some of its properties. sm. 8vo. 280 pp. *Chicago*, [1918]

MILLS, J. Radio communication. Theory and methods, with an Appendix on transmission over wires. sm. 8vo. 216 pp. *New York*, 1917

PAGE, V. W. Storage batteries simplified. Operating principles—care and industrial applications. sm. 8vo. 208 pp. *New York*, 1919

PERNOT, F. E. Electrical phenomena in parallel conductors, vol. 1, Elements of transmission. 8vo. 344 pp. *New York*, 1918

POOLE, J. The practical telephone handbook and guide to the telephonic exchange. 6th ed. sm. 8vo. 748 pp. *London*, 1919

REY, J. The range of electric searchlight projectors. Transl. by J. H. Johnson. la. 8vo. 166 pp. *London*, 1917

RIDEAL, E. K. Industrial electrometallurgy, including electrolytic and electrothermal processes. 8vo. 259 pp. *London*, 1918

RIDGWAY, A. C. Cost accounts, in principle and practice. 8vo. 120 pp. *London, n.d.*

ROSE, W. N. Mathematics for engineers. pt. 1., including elementary and higher algebra, mensuration and graphs, and plane trigonometry. 8vo. 524 pp. *London*, 1918

RUSHMORE, D. B., and LOF, E. A. Hydro-electric power stations. 8vo. 832 pp. *New York*, 1917

SHEPARDSON, G. D. Telephone apparatus. An introduction to the development and theory. 8vo. 354 pp. *New York*, 1917

SLATER, J. A. The Commercial Law of England. 7th ed. sm. 8vo. 251 pp. *London, n.d.*

—— Mercantile Law. 4th ed. 8vo. 464 pp. *London*, 1919

STEINMETZ, C. P. Theoretical elements of electrical engineering. 4th ed. 8vo. 381 pp. *New York*, 1915

—— Theory and calculations of electrical apparatus. 8vo. 502 pp. *New York*, 1917

SUGGATE, A. The elements of engineering estimating. sm. 8vo. 143 pp. *London*, 1912

TAYLOR, W. T., and BRAYMER, D. H. American hydroelectric practice. A compilation of useful data and information on the design, construction and operation of hydroelectric systems from the penstocks to distribution lines. 8vo. 453 pp. *New York*, 1917

TOVEY, P. Balance sheets. How to read and understand them. sm. 8vo. 83 pp. *London, n.d.*

WILLIAMSON, J. G. Counting-house and factory organization. 8vo. 180 pp. *London, n.d.*

WOLLASTON, T. R. Power plant. Installation, upkeep, and economical operation. 8vo. 117 pp. *Manchester*, 1918

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 15. AUGUST 1919. INSTITUTION NOTES. [ISSUED WITH No. 285 OF THE JOURNAL.]

## Session 1919-20.

The first meeting of the Session 1919-20 will be held on Thursday, 13th November, 1919, at the Institution of Civil Engineers, Great George-street, Westminster, S.W. 1, when the President, Mr. Roger T. Smith, will deliver his Inaugural Address.

## Premiums for Papers.

By a recent decision of the Council a certificate suitable for framing will be issued in future to each recipient of a premium awarded by the Institution. Members who desire to receive certificates in respect of premiums awarded prior to the Session 1918–19 should make written application to the Secretary.

## Museum.

Mr. Bernard Crookes has presented to the Institution Museum some interesting apparatus from the laboratory of the late Sir William Crookes, among which are 21 early forms of radiometers and spectrum tubes, a number of tubes containing meteoric gases, 10 early types of glow lamps, an early pattern of telephone receiver, and a McLeod gauge. Mr. G. L. Addenbrooke has also presented a vacuum pump from the laboratory and the Council have purchased the following pieces of apparatus for the Institution Museum:—A large induction coil; a spectrograph including maps, volumes and original negatives; vacuum tubes prepared in connection with the Presidential Address by the late Sir William to the Institution in 1891; a Moissan furnace; an early form of electric arc lamp; a chemical balance, etc.

## I.E.E. Ship Electrical Equipment Regulations.

The above Regulations have now been issued and copies can be obtained from the Secretary at the following prices:—

Bound in blue cloth: 3s. 6d. net (or 3s. 8d., post free).

Bound in American cloth: 2s. 6d. net (or 2s. 8d., post free).

Bound in paper covers: 2s. 6d. (These copies can be supplied, if desired, punched for insertion in Messrs. Walker's loose-leaf pocket-book, No. 64).

## Wiring Rules.

The Wiring Rules Committee have revised the Table of the I.E.E. Wiring Rules (Seventh Edition, March 1916) so as to bring it into line with the latest figures published by the British Engineering Standards Association. Loose copies of the Table can be obtained free of charge on application to the Secretary.

## Students' Premiums.

The Council have awarded the following premiums for papers read before the Students' Sections during the last four sessions:—

| *Value of Premium.* | *Author.* | *Title of Paper and where read.* |
|---|---|---|
| £10 | R. L. SMITH-ROSE | "The Evolution of the Thermionic Valve." (London.) |
| £5 | A. G. EVERETT | "Electric Railway Traction" (London.) |
| £5 | R. T. FLEMING | "Moulded Insulating Compositions." (Manchester.) |
| £5 | R. GATES | "Works Standardization of Pyrometers." (London.) |
| £5 | E. A. GUTHRIE | "Cable Testing in Mines" (Manchester.) |
| £5 | A. G. RAMSEY | "The Aluminium Electrolytic Arrester, with an Introduction on Electrical Disturbances." (London.) |

## Visit to Holland.

At the invitation of the Society of Electricity Works Managers in the Netherlands, of which Mr. J. G. Bellaar Spruyt is President, a deputation representing the Institution visited Holland from the 21st to the 28th September. The deputation comprised Mr. C. H. Wordingham, C.B.E. (President); Mr. Ll. B. Atkinson; Mr. G. Balfour, M.P.; Sir T. O. Callender; Mr. B. Drake; Mr. W. W. Lackie, C.B.E.; Dr. E. W. Marchant; Mr. C. P. Sparks; Mr. W. B. Woodhouse; and Mr. P. F. Rowell (Secretary); and was accompanied by Mr. G. H. Parr of the Department of Overseas Trade.

The visit was of great interest to all members of the deputation, and owing to the kindness of their hosts and to the excellent arrangements made, a very large part of the country was seen, numerous electrical and other works were visited, and matters of more than engineering interest were discussed.

Distinguished official recognition was accorded to the deputation throughout the whole of the visit, culminating in the honour of presentation to Her Majesty the Queen of the Netherlands at her country seat, Het Loo.

At Amsterdam the party was welcomed by the Corporation of the City and by representatives of the Government who had journeyed to Amsterdam especially for this purpose.

At The Hague, at the dinner given in honour of the delegates by the Royal Institute of Engineers, the Ministers of Foreign Affairs and of Public Works, in welcoming the deputation officially on behalf of the Government, stated how much importance Her Majesty's Government attached to the visit and to all that it might mean in the future.

The deputation was also received officially by the Royal Institute of Engineers, by municipal representatives in the principal towns visited, and by the Governors of the various provinces.

The development of electricity supply in Holland has received a considerable stimulus as a result of fuel shortage during the war, and in this development the State, the Provincial Governments, the Municipalities, and the Communal Authorities are all taking part. The share capital of certain company undertakings has been acquired by provincial authorities, and a Government Committee is preparing a Report as to future developments and organization. On this Committee the Society of Electricity Works Managers is represented by Dr. W. Lulofs, the Manager of the Amsterdam Electricity Works. Already, however, very great progress has been made towards the co-ordination of electricity supply throughout the whole country, a development much facilitated by the existence of a standard frequency of 50 cycles. Throughout each province there is a supply of electricity, distributed principally by means of overhead wires, a method which has been much facilitated by the compulsory wayleave powers now possessed by the supply authorities. The generating stations of the various authorities have been, or are being, interconnected to permit the concentration of generation by large units in suitably situated stations, and the development is on a wide scale throughout the country, designed to cater for the needs, not only of the towns and manufacturing industries, but of rural districts; the latter development taking place in conjunction with a general installation of electric pumps to supplement the numerous windmills which form such a prominent feature of the Dutch landscape, and on which the security of the country against flooding has so largely depended.

The Dutch coalfields, situated in the Province of Limburg, have not in the past produced a sufficient output to meet the needs of the country, but it is anticipated that the steps taken to increase the output of coal, and the fuel economy resulting from the electrical developments, will make the country practically self-supporting. The vital importance of this may be appreciated when it is stated that industrial undertakings are now paying 10 times as much for coal as they did before the war. Little coal is being imported from England, it being found cheaper for the moment to import American coal.

The tour made by the deputation was briefly as follows:—

On arrival at Rotterdam on Sunday, the 21st September, the party were met by their hosts and conveyed by motor cars via Delft to Gouda. At Delft is situated the central Engineering College for the whole country. At Gouda a visit was paid to a large cheese store, and the party were entertained to lunch by the municipality.

Thence the route to Amsterdam was taken to show the large polders lying to the south of Amsterdam, with the elaborate system of dykes, waterways at various levels, and pumping arrangements. A disadvantage of pumping by windmill is that at times of heavy rain there is frequently no wind, and the water may lie on the land for some time before it can be removed by this agency. The electrical pumps may, of course, be used at any time desired, and in a recent inundation in North Holland it is understood that their use proved of the highest value and convinced the farmers completely of the benefit of the new system.

At Amsterdam an interesting trip was taken through the town canals. Here, as in other parts of the country, all the heavy merchandise is carried by canal, and the roads used only for the lighter traffic.

In the evening the party were entertained to dinner by the Society of Electricity Works Managers.

On Monday a visit was paid to the harbour at Amsterdam, and the North Sea Canal which connects the port to the North Sea at Ymuiden.

The City of Amsterdam has a population of about 650,000 inhabitants, and was originally reached from the North Sea through the channels of the Zuider Zee. The silting up of this harbour made it necessary that a direct connection should be made to the North Sea, and the North Sea Canal now permits vessels with a draught of 18 ft. to reach Amsterdam. It is lighted electrically to permit safe navigation at night. This canal is being developed by the construction of additional locks at Ymuiden. The extensive waterways of the harbour and the system of canals enables merchandise

to be handled cheaply and rapidly. An extensive system of warehouses, electrically-driven cranes on the various quays, and machinery for loading and discharging coal and ores, were noted. Situated around the harbour are the various industrial works, of which a ship-repairing yard was visited.

A visit was also paid to the floating docks which are arranged to accommodate ships up to 16,500 tons, and these can be raised in 1½ hours.

On the north side of the River Y the new electrical power station of the City of Amsterdam and the central refuse destructor were inspected with great interest. The refuse destructor deals with the refuse from the whole of the city, which is collected by means of barges through the town canals. At the destructor the refuse is unloaded by transporters and delivered to moving belts. On these belts such articles as tin cans, old leather boots, and cotton rags, are picked out and dealt with separately. The tin cans are compressed for easy transport, and the tin is afterwards recovered. The rags are washed and baled; the boots are baled, and it is understood are sent to Belgium, where the good leather is again used. The remainder of the refuse is delivered to the refuse destructor cells, from which sufficient steam is raised to generate at times about 50,000 units daily, this being more than the tramway demand, which is estimated at 30,000 units per day for 370 cars and 310 trailers. These destructors, working under forced draught, make it possible to raise the temperature of the cells to a high degree. The steam raised is conveyed to the adjoining electricity works, and it is understood that during the war a considerable proportion of the electricity works' output was generated from steam raised in this way, though, as in destructors in other countries, it appeared that the amount of steam raised per ton of refuse was not great, and that the supply was variable. The mechanical apparatus for handling the refuse and for dealing with the discharge of the clinker from the cells was excellently designed, and the whole works were a credit to the city.

In the electricity works three-phase current is generated at a pressure of 10,000 volts by means of steam turbines and watertube boilers. Further extensions were in progress, and the deputation were much interested in the details of the station construction and operation.

In the evening the deputation was entertained by the municipality of the City of Amsterdam.

On the 23rd September a visit was paid to a large diamond-cutting factory in Amsterdam, wholly electrically driven.

Particulars of the extraordinary development of electricity supply in Amsterdam were furnished by Dr. Lulofs. It appears that out of 140,000 houses or apartments 110,000 are provided with electric light, the pre-war connections being 30,000. Additional connections are being made at the rate of 500 a month. This large increase has been accelerated by the difficulties of the inhabitants in obtaining any sort of light during the war; neither gas nor candles were available, and the Corporation decided that every house should be provided with at least one lamp, and with this object free wiring has been introduced.

From Amsterdam the party journeyed to The Hague, where there was a reception by the President of the Royal Institute of Engineers, Dr. Croll, and Mr. H. Doijer, the President of the Electrical Section, and later in the day a dinner at which were present, in addition to members, the members of the Council of the Royal Institute of Engineers, His Excellency Dr. H. A. van Karnebeek, Minister of Foreign Affairs; His Excellency Mr. H. A. van Ijsselteyn, Minister of Public Works; and Mr. Arnold Robertson, British Chargé d'Affaires at The Hague. At the dinner His Excellency Dr. van Karnebeek, Mr. Doijer, and others proposed toasts, and the President (Mr. C. H. Wordingham), Sir T. O. Callender, and Mr. C. P. Sparks, replied.

The Government representatives, as stated above, officially welcomed the deputation, and the tenor of the speeches at this and all other ceremonials evinced the greatest friendship towards the British nation, and both by words and deeds it was made clear to the deputation that they were heartily welcome.

Mr. Doijer, who is a member of our own Institution, in his speech pointed out that among the electrical machinery in Holland, English articles play an unimportant part, 80 or 90 per cent being of German or Swiss origin. He said: "Your tendency to good workmanship of electrical articles is on an average more pronounced than that of the German and Swiss firms, but their art of manufacturing in large quantities is superior to yours, which makes their products less expensive. Your knowledge of electrical materials is more profound than that of your competitors, but their faculty and facility to calculate is more at the fingers' ends of their average man, enabling them, with all the dangers attached to it, to approach nearer to the minimum allowable dimensions of material, which makes their articles again a little cheaper. Your insight into the difficult electrical engineering problems is in my opinion superior to theirs, but their organization to introduce their products over here is certainly more systematized than yours. To express it in a few words: you excel in the character of the individual, your competitors excel in the organization of the masses. And to finish up, did not they induce our young electrical engineers to live with them in Germany and Switzerland in their factories and offices, inspiring them after a few years to return to Holland, imbued more or less with their interpretation of electrical problems? I told you that this is my personal view of the matter. If I am wrong I certainly gave you my honest opinion and nothing but my honest opinion. Now turning again my official face to you as President of the Dutch Institution of Electrical Engineers, I can only say this, that if you want to improve to your favour the balance of imported electrical articles among the countries surrounding Holland, you will be perfectly welcome and you will have our best wishes. Our country is as yet too small to make every electrical thing we want ourselves, and *if* we have to import from abroad there is no reason why we should not wish to receive just as many products from your country as from any other country. But the articles will have to be of the same quality and about the same price. They may have

been up till now of the same quality or even sometimes better, but they were higher in price."

On the 24th September the central station at The Hague was visited. Mr. G. J. F. Bakker, the Manager of The Hague Works, and also Secretary of the Society of Electricity Works Managers, explained the developments of electricity supply in The Hague, and a very interesting morning was spent in inspecting the works, the foundation problems in these works, as in others, being of particular interest, due to the water-logged and loose nature of the sub-soil. Here, as elsewhere, large use was being made of reinforced concrete for constructional work.

Later in the day a visit was paid to Poeldijk, where a horticultural show was in progress. The glass-houses of a large grape grower were also visited, electric light and electric power for agricultural purposes being in evidence everywhere.

Scheveningen was also visited, and in the evening the party left by train for Maastricht.

At The Hague and on the journey from Rotterdam to Amsterdam, the electric railway from Rotterdam to The Hague was seen. This railway is an example of the high-pressure alternating-current system, the overhead contact wires being at a pressure of 10,000 volts.

On the 25th September the party journeyed from Maastricht to the State Coal Mine " Emma," passing on the way various other collieries. The question of nationalization of the mines and key industries has been carefully studied in Holland, and naturally in a small country it is more easily carried into effect, but even there a compromise has been adopted which should be of interest to those concerned with this thorny problem in this country. The " Emma " mine is registered as a Company with a board of directors, but the majority of the shares are held by the State. Thus the advantages of private management are secured whilst the State retains the power to dictate its policy.

The present output of the Dutch coalfield is four million tons a year, of which approximately one-half is produced by the State mines, the other half by private enterprise. It is anticipated that the output will be substantially increased, and that in the near future some eight million tons will be produced. The surface works of the mine were inspected in detail, including the electric winding gears for which a d.c. supply at 1,200 volts is used, and also the three-phase electric power station, which supplies current not only to the mines but also to the Province of Limburg and the town of Maastricht. The system of transmission mains from this station is almost wholly underground. An interesting construction of ferro-concrete cooling towers with hyperboloidal shells was noticed, these towers being designed by the engineer of the mines. The developments of the mines and other interesting particulars were explained to the party by the colliery officials, and visits were paid to the colliers' bath-houses and to the miners' village, the houses of which were in pleasant surroundings and were of good appearance.

One of the difficulties of developing the mines has been to obtain and retain the necessary labour, and it may be for this reason that the houses are let at low rents, it being stated that houses which had cost during the war the equivalent of £650 to build were let at a rental of from 20s. to 30s. a month.

The coal produced is stated to have excellent coking properties, and batteries of coke ovens are being erected. During the war a neighbouring deposit of lignite was utilized for power production, and this was still in use, the lignite being excavated by surface working in the neighbourhood of the " Emma " pit.

On leaving the collieries the party journeyed to the house of Baron de Marchant d'Ansembourg, where they were entertained by the Baron and Sir Alphonse Michiel van Kessenich.

Returning to Maastricht the deputation were entertained at dinner by the electricity supply company of which Mr. Bellaar Spruyt is manager.

On the 26th September the party journeyed along the great military road to the north along the valley of the Maas. The towns and villages passed through had the invariable appearance of prosperity and cleanliness which is so marked a characteristic of the country.

At Nijmegen the ferry was crossed, and at Arnhem the party was received by the Provincial Authorities at lunch. Both Arnhem and Nijmegen are towns of great beauty.

The journey was resumed to Apeldoorn and the palace of the Queen, Het Loo. The deputation was received by Her Majesty the Queen and her Consort, Prince Henry, and the members were presented by Mr. Arnold Robertson, British Chargé d'Affaires at The Hague. The Queen evinced great interest in the views of the deputation, and inquired of each the matters of particular interest to him in her country. The party were afterwards entertained to tea, and continued their journey to Zwolle, where they were received by the provincial electricity supply authorities. The journey to Groningen was completed by train.

Throughout the whole of the country the development of the supply of electricity was evident. Every little village had electric light distributed by means of overhead wires, the construction being of the simplest possible character.

On the 27th September at Groningen a visit was paid to a straw-board factory worked on the co-operative system, the shareholders being the farmers who supply the straw. The machinery is driven by electricity from the public supply, and with the exception of the paper machines, in which a fine adjustment of speed is required (obtained by direct-current motors), the whole factory is equipped with alternating-current motors. The factory, which contains 90 motors of from 5 to 105 h.p., is an important consumer of the Groningen power supply station, absorbing nearly one-half of the present output.

The central station at Groningen supplies the towns and the Province, and in addition furnishes a supply in bulk to the Province of Friesland. Transmission, as elsewhere, is at 10,000 volts by means of overhead lines and cables, but a 50,000-volt line is in course of construction ; distribution is at 3,000 volts and 380 volts, the neat design of the overhead distribution lines being particularly noticeable.

An example of recent developments in conjunction with the public electric power supply was inspected at the Electra pumping station, in the north of the province of Groningen. The pumping station is designed to deal with the rainfall over an area of 94,000 hectares, which is lifted from the low lands to the Reitdiep Canal, from whence it is discharged to the sea, through locks, at low tide.

The pumping station is some distance inland to permit of the utilization of a large area of low-lying land as a reservoir or storage basin, and so that the flow of water from the canal may be effective in preventing the silting up of the channel used for navigation. Incidentally, better foundations and lower horse-power for pumping were the result. The reservoir at Lammerbuen is 110 hectares in area.

The station now in course of construction is equipped with three pumps, each capable of delivering 950 cubic metres per minute against a head of from 0 to 1·75 metres.

The discharge is submerged, and the pumps are designed to run at a constant speed to deliver against a varying head without serious loss of efficiency. Tests of a similar type of pump showed an efficiency of from 77 to 50 per cent over the working range. The pumps are of the axial turbine type, with fixed guide blades on the delivery side. Each pump is driven through gearing by a 550-h.p. motor supplied with three-phase current at 3,500 volts. The supply is transmitted from Groningen at a pressure of 10,000 volts, though a higher transmission voltage is projected for the future.

Temporarily a 1,500-kw. generating set is being installed at the pumping station. The working hours of the plant depend of course on the rainfall; it is not anticipated that the plant will run for more than 30 days in the year. The effect of stand-by charges on the cost is therefore of the greatest importance.

At Zoutkamp two interesting examples were inspected, by the courtesy of Messrs. Mansholt, of the use of electricity supply for agricultural purposes. All the farm buildings were electrically lighted, and electric power was used for a variety of purposes, including the stacking in the large barns of hay, straw, and clover by means of a simple form of motor-driven elevator and transporter. The price of good farming land was stated to be about £200 per acre.

The final day was spent by a portion of the party in a journey through the Friesland Lake District. Travelling by motor car to Schuilenberg, the party was met by the Governor of the Province, and representatives of the Provincial Government and of the Electricity department.

The journey through the lakes was made by motor yacht. At Kruiswater the foundations of the steel towers carrying an overhead line across the canal at a height of 33 metres were inspected.

At Grouw the overhead lines cross the water by a span of 190 metres, carried by steel towers 48 metres high.

At Sneek the boats were left for the train to Stavoren, the Zuider Zee being crossed to Enkhuizen and Amsterdam finally reached by train. The party returned to England via Flushing.

Summarizing the impressions gained, it appears that the rapid development of electricity supply will call for a considerable extension of the generating stations and transmission systems, in which British manufacturers should take their part. The development of electrical manufacturing undertakings in the country is growing, but apparently not so rapidly as the demand for plant.

From the point of view of British electrical manufacturers it is clear from the installations which were visited that the Dutch electrical engineers relied before the war almost entirely on German machinery for their generating stations and motor equipment, with the notable exception that a considerable amount of British cables have been laid in Holland.

During the war period owing to the inability of British manufacturers and German manufacturers to supply, a great impulse has been given to the production of electrical plant in Holland, and turbo sets built by the "Stork" Company, in collaboration with Brown Boveri of Switzerland, are in operation or being erected in some of the modern stations, whilst other firms are specializing in smaller plant such as motors, etc.

British cables by some of the principal firms were in considerable evidence, drums being seen in various towns and villages throughout the country. Although it is clear that the Netherlands Cable Factory of Delft is equipped to supply, and is supplying, very considerable quantities of large cables, the Dutch Cable Factory of Amsterdam appears at present to be confining itself to the supply of smaller wires for internal installations, etc.

As far as could be gathered from conversation, British and German prices both for machinery and for cables were in favour of British manufacturers if the £ sterling and the mark were at their original parity, but the great discount at which the mark stands enables Dutch buyers to obtain a much more favourable price stated in guilden from German manufacturers than from our own, and at the present moment German quotations are being made so that this difference may even amount to 20 per cent. On the other hand, deliveries from Germany still seem an uncertain quantity, and for quick deliveries the probability is that the British manufacturers could obtain the orders, particularly if they could state their price c.i.f. at a Dutch port.

The general impression gained by manufacturers who took part in the visit was that it would probably be a wise policy to endeavour to set apart some proportion of their manufacturing facilities to supply the Dutch market.

The extensive distribution in rural districts by means of overhead wires is made possible by the lenient regulations as to the method of construction, and by the compulsory wayleave powers possessed by the supply authorities. Any restrictive regulations issued were stated to apply only to companies and not to municipal undertakings.

The extensive use of electricity for agricultural and domestic purposes should encourage the forward policy in this country.

Electric power supply is placed in an advantageous position by the high price of fuel; the national resources of coal are not great, and peat, though extensively

used domestically, is of little present value for power purposes. The price of peat to private users is 1,000 pieces for 40 guilden, i.e. twice the pre-war price.

Many conditions are favourable to electric power supply and the Dutch engineers are taking full advantage of them.

Everywhere was evidence of the closest co-operation between the supply authorities, companies, municipalities, and provincial authorities, and in the industries associated with agriculture, such as sugar factories, dairies, and the like, a number of the undertakings are working on the co-operative system.

Mr. Wordingham summed up the matter in his concluding speech at Groningen in the words : " Co-operation is the keynote of the country."

The thanks of the deputation must be expressed to all who welcomed, entertained, and instructed them. In a multitude of hosts, each a host in himself, it would be almost invidious to mention names, and one must be content to express to Mr. J. G. Bellaar Spruyt, the President of the Society of Electricity Works Managers, the thanks of the party for the Society's kindness. To quote from one of Mr. Wordingham's speeches : " Nothing was too great for them to do, no detail too small to attend to." Thanks are also due to the Royal Institute of Engineers, to the representatives of the Provincial Governments and of the Municipalities, and to those gentlemen associated with the various industrial concerns visited, and to all those who joined with them.

Finally must be recorded the deep appreciation of the deputation of the honour paid to them and to the Institution they represented, by Her Majesty the Queen of the Netherlands.

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The following note has been received from one of the members of the party :—

As there seems some misapprehension as to the effect of the adverse rate of exchange affecting the power of a country like Germany to purchase its raw materials abroad, it may be worth while to point out that in a purchase by a country of raw materials abroad for the purpose of manufacture and re-export, the question of exchange rate practically cancels out and the item that is really affected is that part of the cost, labour, management, use of machinery, etc., which are all internal to the exporting country, and which part of the cost is purchased at an actually low value by the external buyer. Thus, for instance, in the case of paper-insulated cables, Germany has in the past purchased copper and paper in external markets, and for her own consumption would be unfavourably placed buying to-day with the depreciated mark, but on re-export these materials reach the external market again at the external market price, while all the other items mentioned reach the external market at a lower price than similar goods from British manufacturers.

## Electricity (Supply) Bill, 1919.

The following statement by the Council has been sent to the Prime Minister and to the members of both Houses of Parliament :—

The Institution of Electrical Engineers is the representative body which comprises within its membership British electrical engineers engaged in every branch of the electrical profession and industry. The Council recognize the national importance of the question of electricity supply in its bearing on fuel economy and cheap power for industry, and every member of the Institution is directly or indirectly concerned in a greater or less degree with the effects of the Electricity (Supply) Bill now before Parliament. On these grounds the Council feel that some expression of opinion by them on behalf of the Institution is called for on the principles underlying the Bill and on the necessity for legislation.

Before making their observations the Council have conferred with the Territorial Centres of the Institution and with the principal representative associations concerned, either as suppliers or as consumers of electricity, and the conclusions set forth below find either unanimous or majority support.

It is recognized that great injury to the national interest has resulted from ill-considered electrical legislation in the past, the effect of which has been to check the technical and commercial progress of this key industry in all its departments.

When, therefore, fresh legislation is introduced by the present Bill, its provisions are examined at once with hope and anxiety, in so far as they promise to remedy the defects of past legislation or threaten to impose new restrictions.

The proposal in the Bill to appoint Electricity Commissioners is universally welcomed, in so far as it provides for simplified procedure and control. Such an authority should impartially survey the conditions in any district from the point of view of the best interests of consumers, should remove artificial obstacles to the cheapening of supply, and should, by co-ordination of existing resources, not only effect improvements itself, but afford greater opportunity for progressive development by the various undertakings engaged.

The Council recommend that all the Commissioners should give whole-time service, and that they should themselves appoint an Advisory Council, membership of which should be restricted to persons possessing expert qualifications.

There is general approval, also, of the charging of such Commissioners with power to undertake and promote research.

Such opportunity for unimpeded enterprise has never before been granted to the supply authorities, and it is therefore urged that they should be permitted and encouraged to do their utmost for the public service under the general jurisdiction of the Commissioners, before that body proceeds, as contemplated by the Bill, to set up District Electricity Boards.

Especially in view of the widely varying local conditions, it is felt that the Bill should not attempt to impose a rigid system of uniformity for all parts of the country, and that the Commissioners should be given latitude to facilitate schemes suitable for each district, giving first attention to the co-ordination and logical extension of existing systems.

There is general opposition to the proposed terms

for the purchase of generating stations and main transmission systems, and it is urged that Parliament should not break faith with those who have invested their capital on the strength of the powers conferred by earlier legislation.

It is also strongly urged that all whose positions may be adversely affected in consequence of changes brought about by the Bill, whether on the staff or as wage earners, should be liberally dealt with, and that if representation is given to labour on any governing body, the engineering staffs should be similarly represented, and should also have the right to refer to arbitration for the settlement of differences arising out of their employment.

Having regard to the admittedly great importance of electricity supply, and the fact that practically every industry in the country is largely concerned therein, it is emphatically the opinion of the Council that the Electricity Commissioners should be responsible to Parliament through the President of the Board of Trade and should not be under the Ministry of Ways and Communications.

Signed on behalf of the Council,
C. H. WORDINGHAM,
*President.*

*July* 1919.

## Annual Dinner.

The following replies were received to the greetings sent in accordance with the proposal of the President at the Annual Dinner (see *Journal I.E.E.*, 1919, vol. 57, p. 534) :—

BRUSSELS, 2 *July*, 1919.

Deeply appreciative of your friendly courtesy, the members of the Société Belge des Electriciens join most heartily in the first celebration of their brothers the British Electrical Engineers, and send them their most cordial greetings.

PIÉRARD, *President.*

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PARIS, 1 *July*, 1919.

Deeply moved by the affectionate thoughtfulness on the part of their fellow-members of the British Institution of Electrical Engineers, the members of the Société Française des Electriciens send them fraternal greetings on the occasion of their first celebration, and rejoice with them over the fact that the Peace Treaty has been signed.

MAZEN, *President.*

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MILAN, 3 *July*, 1919.

The Members of the Associazione Elettrotecnica Italiana return to their English colleagues their expression of warm friendship, already traditional, which the present Allied victory has happily scaled.

FERRARIS, *President.*

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TOKIO, 9 *July*, 1919.

Your cordial greetings heartily appreciated and reciprocated.

NAMBA, *President, Denkigakkai.*

## Royal Engineers.

The Secretary has been asked to give publicity to the following :—

PROCEEDINGS OF MEETING OF THE R.E. CORPS COMMITTEE HELD IN ROOM 230, WAR OFFICE, 21ST JULY, 1919 (IN ACCORDANCE WITH THE RESOLUTION AGREED TO AT THE ANNUAL CORPS MEETING ON 14TH JUNE, 1919).

*Present.*—Maj.-Gen. Sir P. G. Twining (D.F.W.), Maj.-Gen. S. H. Powell (C.E. Forces in Great Britain),* Maj.-Gen. L. Jones (C.E. Eastern Command),* Brig.-Gen. T. A. H. Bigge (A.A.G., R.E.), Brig.-Gen. A. L. Schreiber (C.S.M.E.),* Brig.-Gen. G. A. S. Cartwright (C.E. Aldershot),* Brig.-Gen. A. W. Roper (I.R.E.), Brig.-Gen. G. Walker (C.E. London),* and Major L. Chenevix Trench (Hon. Sec. R.E. Committee).

*Agenda.*—To discuss Maj.-Gen. Sir P. G. Twining's proposal :—

> "That in the opinion of this Committee it is not only desirable but is necessary that all possible steps be taken towards preserving the feeling of friendship and camaraderie which existed during the war between the Regular Corps of R.E. and the Special Reserve, Territorial and Temporary Officers and men, and that as a means to this end the R.E. Institute, and as far as possible other Corps Institutions, should be thrown open to these officers, and that steps be taken to bring this as far as possible to the notice of all such officers."

*Acta.*—The opinions of the Presidents of the several R.E. Corps Institutions were read, and following conclusions reached :—

| | |
|---|---|
| R.E. Band Fund .. | The deed of settlement in the one case and Army Orders in the other preclude the possibility of an extended membership. |
| R.E. Widows Society | |
| R.E. Institute .. | Already accepts all R.E.Officers, including S.R., T.F., and T.C. |
| R.E. Charitable Fund | Already accepts all R.E., including S.R., T.F., and New Armies. |
| R.E. Games Fund .. | Terms of admission to be considered by Games Committee. |
| R.E. Entertainment Fund .. .. | Officers of the T.F. and S.R. and Temporary Officers will be welcomed at the Annual Dinner and the Annual Evening Entertainment, and the Luncheon Club tent will be open to them. |
| R.E. Dinner Club .. | |
| R.E. Luncheon Club | |
| R.E. Old Comrades' Association | Already open to all Members of Corps of R.E., including S.R., T.F., and New Armies. |

It was further agreed that the above should be advertised in the *R.E. Journal*, and that the Engineering

* Specially attended with power to vote, in accordance with resolution dated 3rd July, 1919.

Institutions, i.e. the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Surveyors' Institution, and the Association of British Architects, should be informed early through the medium of their secretaries of the decisions taken and should be asked, as far as lies in their power, to disseminate this information among their members.

## Roll of Honour.

(Fourteenth List. *)

**Killed in Action.**

| | | |
|---|---|---|
| Reynolds, Gunner O. B. | New Zealand Artillery | Student |
| Winkley, Lieutenant S. H. | Royal Air Force | Student |

**Killed.**

| | | |
|---|---|---|
| Bannister, Captain E. G. | Royal Air Force | Student |
| Hayne, Captain E. T., D.S.C., D.F.C. | Royal Air Force | Student |
| Wright, Lieutenant C. V. C. | Royal Air Force | Associate Member |

**Died.**

| | | |
|---|---|---|
| Elkins, Sapper C. A. I. | Royal Engineers | Associate Member |
| Laurie, Captain D. S., O.B.E. | Royal Engineers | Associate Member |
| Murphy, Lieutenant G. H. | R.N.V.R. | Graduate |
| Prince, Lieutenant G. R. D. | Royal Engineers | Associate Member |
| Twigg, Private J. H. | Royal Army Service Corps | Associate Member |
| Wilson, Lieutenant G. H. | Royal Engineers | Associate Member |

## Military Honours Awarded.

(Fifteenth List.†)

**K.B.E.**

| | | |
|---|---|---|
| Brown, Lieutenant A. Whitten | Royal Air Force | Associate Member |

**C.M.G.**

| | | |
|---|---|---|
| McNaughton, Brig.-Gen. A. G. L., D.S.O. | Canadian Field Artillery | Associate Member |
| Warrington-Morris, Lieut.-Col. A. D., O.B.E. | Royal Air Force | Associate Member |
| Webb-Bowen, Colonel H. E., D.S.O., T.D. | Royal Engineers | Associate Member |

* See *Journal I.E.E.*, vol. 54, pp. 64, 447, and 675; vol. 55, pp. 55, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 7, p. 29; No. 9, p. 4; No. 11, p. 20; and No. 12, p. 23.

† See *Journal I.E.E.*, vol. 54, pp. 306, 518, and 674; vol. 55, pp. 56, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 6, p. 24; No. 7, p. 30; No. 9, p. 4; No. 12, p. 23; and No. 14, p. 30.

**C.I.E.**

| | | |
|---|---|---|
| Trench, Lieut.-Col. A. H. C. | Royal Engineers | Associate Member |

**C.B.E.**

| | | |
|---|---|---|
| Jenkin, Lieut.-Col. C. F., M.B.E. | Royal Air Force | Member |
| McClymont, Lt.-Col. R. A., D.S.O. | Royal Artillery | Associate |
| Morcom, Lieut.-Col. R. K., M.B.E. | Royal Engineers | Member |
| Simpson, Colonel L. S., D.S.O. | Royal Engineers | Associate |

**O.B.E.**

| | | |
|---|---|---|
| Alkin, Captain R. L. | East Lancashire Regt. attd. R.E. | Member |
| Archer, Major J. O. | Royal Air Force | Associate Member |
| Bell, Major H. | Royal Engineers | Member |
| Brook, Major R. V. C. | Royal Air Force | Associate Member |
| Carden, Major E. D. | Royal Engineers | Associate Member |
| Chandler, Major A. F. N. | Royal Army Ordnance Corps | Graduate |
| Cooper, Lieut.-Col. V. B. D. | Royal Engineers | Member |
| Cottle, Major P. J., M.C. | Royal Engineers | Associate Member |
| Crowther, Commander W. R. D. | Royal Navy | Graduate |
| Dewar, Major M. B. U. | Royal Engineers | Associate Member |
| Dunsheath, Captain P. | Royal Engineers | Associate Member |
| Goad, Major D. | Royal Air Force | Associate Member |
| Harris, Captain L. J. | Royal Engineers | Associate Member |
| Hirtzel, Major C. H. A. | Royal Air Force | Associate Member |
| Humphreys, Captain P. H. I. | Special List | Associate Member |
| Kilby, Captain J. W. | Royal Engineers | Student |
| Masters, Captain F. H. | Royal Engineers | Associate Member |
| Mohr, Major S. M., M.C. | Notts and Derby Regt. | Associate Member |
| Poulton, Captain F. C. | Royal Army Ordnance Corps | Associate Member |
| Purves, Major T. F. | Royal Engineers | Member |
| Pyne, Major F. D. | Royal Engineers | Associate Member |
| Redman, Major S. G. | Northumberland Fusiliers | Member |
| Rich, Major T. | Royal Engineers | Associate Member |
| Richardson, Major H., M.C. | Royal Engineers | Member |
| Rodwell, Major J. T. | Royal Air Force | Student |
| Shaw, Lieutenant F. B. | R.N.V.R. | Member |
| Trevett, Major C. G. | South African A.S.C. | Associate Member |
| Thornycroft, Lieutenant O. | R.N.V.R. | Associate Member |

| | | |
|---|---|---|
| Whitaker, Captain G. B. | Royal Engineers | Associate Member |
| Williamson, Major G. W., M.C. | Royal Air Force | Member |

**M.B.E.**

| | | |
|---|---|---|
| Allingham, Lieutenant G. C. | Royal Engineers | Member |
| Chandler, Captain C. K. | Royal Air Force | Graduate |
| Colbeck, Captain P. | Royal Air Force | Associate Member |
| Deedes, Captain J. G. | Royal Engineers | Student |
| Fulcher, Lieut. E. W. P. | Norfolk Regt. attd. R.E. | Associate Member |
| Goodall, Captain F. H. | Royal Engineers | Associate Member |
| Gunton, Major H. C. | Royal Engineers (V.) | Member |
| Hatch, Lieutenant W. A. | Royal Engineers | Associate Member |
| Headwards, Lieutenant H. H. | Royal Engineers | Student |
| Lisle, Lieutenant A. | Royal Engineers | Associate Member |
| McDougall, Lieutenant A. | Royal Engineers | Associate Member |
| Searle, Captain A. M. | Royal Engineers | Associate Member |
| Shallis, Major B. | Royal Engineers | Associate Member |
| Thomson, Major K. J. | Royal Engineers | Associate Member |
| White, Major B. G. | Royal Engineers | Member |
| Wooler, Lieutenant L. S. | Royal Artillery | Student |

**M.C.**

| | | |
|---|---|---|
| Bamford, Captain H. M. | Royal Engineers | Associate Member |
| Bond, Captain H. | Royal Garrison Artillery | Associate Member |
| Bullpitt, Captain K. D. | Tank Corps | Associate Member |
| Clarke, Lieutenant C. V. | South Staffordshire Regt. | Student |
| Dermer, Major L. H. C. | Royal Engineers | Associate Member |
| Hartley, Captain J. B. | Royal Garrison Artillery | Associate Member |
| Hird, 2nd Lieut. C. H. | Royal Engineers | Associate Member |
| Krohn, Major V. R. | Royal Field Artillery | Student |
| Owen, Captain R. E. L. | Royal Engineers | Associate Member |
| Scott-Taggart, Lieutenant J. | Royal Engineers | Student |
| Slingo, Captain P. E. | Royal Engineers | Associate Member |
| White, Lieutenant J. | Australian Engineers | Associate Member |

**Air Force Cross.**

| | | |
|---|---|---|
| Nelson, Captain G. D., D.S.C. | Royal Air Force | Associate Member |

**Meritorious Service Medal.**

| | | |
|---|---|---|
| Clayton, Mech. Staff-Sergt. A. E. | Royal Engineers | Associate Member |
| Judkevitch, Sergeant R. M. N. | Royal Engineers | Student |

**Mentioned in Despatches.**

| | | |
|---|---|---|
| Aspland, Lieutenant G. D., M.C. | Royal Engineers | Graduate |
| Bamford, Captain H. M. | Royal Engineers | Associate Member |
| Bell, Major H. | Royal Engineers | Member |
| Brotherton, Lieutenant C. E. | Royal Engineers | Associate Member |
| Chandler, Major A. F. N. | Royal Army Ordnance Corps | Graduate |
| Cottle, Major P. J., M.C. | Royal Engineers | Associate Member |
| Davidson, Lieut.-Col. A. E., D.S.O. | Royal Engineers | Associate Member |
| Ellis, Captain M. I. W. | Royal Artillery attd. R.E. | Associate Member |
| Geipel, Lieutenant K. S., O.B.E. | Royal Engineers | Associate Member |
| Harris, Captain L. J. | Royal Engineers | Associate Member |
| Hirtzel, Major C. H. A. | Royal Air Force | Associate Member |
| Holland, Major H. N. | Royal Army Service Corps | Associate Member |
| Kirkby, Lieut.-Col. H. M., M.C., D.C.M. | Royal Army Ordnance Corps | Associate Member |
| Leak, Captain B. W. | Royal Garrison Artillery | Associate Member |
| Leisbman, Major G. A. B. | Royal Field Artillery | Student |
| Lintott, Major A., L., D.S.O. | London Regt. | Graduate |
| Long, Major R. F., M.C. | Royal Field Artillery | Associate Member |
| Owen, Captain R. E. L. | Royal Garrison Artillery | Associate Member |
| Peattie, Lieutenant J. D. | Royal Engineers | Associate Member |
| Percy, Lieutenant H. L. | Royal Engineers | Member |
| Pitkeathly, Colonel J. S., C.V.O., C.B.E., D.S.O. | Royal Engineers | Associate Member |
| Pope, Major W. G. T., M.C. | Royal Engineers | Associate Member |
| Rogers, 2nd Lieut. A. H. E. | Royal Engineers | Associate Member |
| Rorke, Major A., M.C. | Royal Engineers | Associate Member |
| Sanders, Lieut.-Com. H. E. | R.N.V.R. | Associate Member |
| Scott-Taggart, Lieutenant J. | Royal Engineers | Student |
| Sheppard, Major J. H. D. | Royal Army Ordnance Corps | Graduate |
| Simpson, Colonel L. S., D.S.O. | Royal Engineers | Associate |
| Sizer, Lieutenant N., M.C. | Royal Engineers | Associate Member |
| Smith, Major T. V., M.C. | Royal Air Force | Member |

| | | |
|---|---|---|
| Stevens, Major E. J. | Royal Artillery attd. R.E. | Associate Member |
| Stuart, Major-Gen. Sir A. M., K.C.M.G., C.B. | Royal Engineers | Member |
| Thomson, Major K. J. | Royal Engineers | Associate Member |
| Trench, Lieut.-Colonel A. H. C. | Royal Engineers | Associate Member |
| Webb-Bowen, Colonel H. E., D.S.O., T.D. | Royal Engineers | Associate Member |
| Williams, Captain R. A., M.C. | Royal Engineers | Associate Member |

**Legion of Honour, Chevalier.**

| | | |
|---|---|---|
| Fuller, Major A. C. | Royal Engineers | Associate Member |

**Military Order of Aviz, Chevalier (Portugal).**

| | | |
|---|---|---|
| Ward, Lieutenant E. J. | Royal Irish Regt. | Associate Member |

**Croix de Guerre (France).**

| | | |
|---|---|---|
| Marx, Captain R., M.C. | Royal Field Artillery | Student |
| Stone, Lieutenant H. J., M.C. | Royal Engineers | Student |

**Croix de Guerre (Belgium).**

| | | |
|---|---|---|
| Lisle, Lieutenant A. | Royal Engineers | Associate Member |

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2, Amplifier (C. Mark III).
5, Power-buzzer-amplifier.
6, Wavemeter, heterodyne.
7, Fullerphone, Mark III.
8, W.T. sets, trench, continuous wave. Receiver, Mk. III. Selector. Transmitter, Mks. III, III*. Testing set, W.T. sets, trench. C.W. transmitter, Mks. III, III*.
9, Buzzer sets, W/T training.
10, Amplifier. (C. Mk. IV).
11, W.T. sets, field, C.W., Mk. III. Receiver, Mk. IV.
12, Unit H.T., W.T., 30-watt, Mk. I. Unit H.T., W.T., rectifier two valve.
13, Wavemeter, 750–3,000 metres. 125–1,600 metres. 300–4,000 metres.
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# THE TENTH KELVIN LECTURE.

## THE DYNAMICAL THEORY OF ELECTRIC ENGINES.

By LLEWELYN B. ATKINSON, Member.

(*Lecture delivered before* THE INSTITUTION, 7 *November*, 1918.)

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### INTRODUCTION.

Eleven years ago, in 1907, there passed away at the age of 83 one of the greatest intellects of his own and indeed of all times, Lord Kelvin, a founder and Past President of this Institution and to a large degree a creator of the science of which this Institution is the exponent.

As a fitting memorial to his name, and to commemorate and keep alive the memory of this great man, the Institution inaugurated an annual lecture to be called the Kelvin Lecture. The Council have done me the honour to invite me to give to the Institution this, the tenth Kelvin Lecture, and, whilst I deeply appreciate

the honour, I am also strongly conscious of the difficult task I have undertaken. If I contemplate the scientific attainment and standing of those who have preceded me as Kelvin lecturers, I realize that it is by no means an easy task to maintain the standard by which such lectures must be judged. I believe I am correct in saying that all the previous lecturers had had the privilege of attending Lord Kelvin's lectures in the Glasgow University or of being associated closely with him in some of the work of his life. I can claim neither of these advantages; my knowledge of Kelvin and his work is that arising only from his published writings, and from having, from time to time, heard him read papers or give public lectures before scientific societies.

The prodigious growth of electrical science and its applications makes it difficult for the younger generation of electrical engineers to realize what Kelvin was or what he did for electrical science between the years 1845 to 1895, and in my experience there are many of the present generation of electrical engineers who are quite ignorant of some of the scientific truths which Lord Kelvin presented to the world. I therefore purpose in this lecture to concentrate attention upon one of such truths, and its results, which I think is and has been overlooked and ignored.

## Mechanical Values of Distributions of Electricity, Magnetism, and Galvanism.

In 1853 Lord Kelvin, then Professor William Thomson, read a paper before the Glasgow Philosophical Society (1853, vol. 3) on the "Mechanical Values of Distributions of Electricity, Magnetism, and Galvanism" in which he, for the first time, enunciated the principle that every distribution of electricity, magnetism, or electric currents has a definite energy value which is calculable, and he gave expressions for some of these values. In the year 1860 the second edition of Nichol's "Cyclopædia of Physical Sciences" was published, in which the articles on Electricity and Magnetism were largely written by Kelvin; and one of these articles on "The Dynamical Relations of Magnetism" further developed this subject. In "Collected Mathematical and Physical Papers," vol. i, 1882, Kelvin republished the Glasgow paper with additions from the articles in the Cyclopædia, and with some further additions then made. As will be shown later on, the starting-point so far as his publications went, was the 1853 paper. Kelvin states that this question of the definite mechanical value of distributions of electricity, etc., had been first solved by him in 1845, and so it is clear that his mind had been working on this matter for some years before he published the 1853 paper. He also tells us that some suggestions in the same direction had been made by Joule in 1840, and that the general idea had been put forward by Helmholtz in 1847 in his memoir on "The Conservation of Energy." Nevertheless, this paper of Kelvin's was the first definite statement giving the method of calculating the energy related to electrical and magnetic conditions. The article in Nichol's Cyclopædia carried the matter, so far as concerns the definite calculations relating to the electromagnetic case, a good deal further than the original paper, and in particular it is worth while to reproduce Part III of the article, which will be done below.

The original paper is divided into three heads. The first deals with electrostatically charged bodies. He says:—

"The mechanical value of any electrification of a conductor has a perfectly definite character or may be calculated by means of formulæ demonstrated in this communication.

"The simplest case is that of a single conductor insulated at a distance from other conductors, or with only uninsulated conducting matter in its neighbourhood. In this case the mechanical value of the electrification of the conductor is equal to half the square of the quantity of electricity multiplied by the capacity of the conductor." *

Later on he gives the general case of a system of electrified conductors and shows that the general expression for the energy W is

$$W = \tfrac{1}{2} \Sigma (Q V),$$

where Q is the quantity of electricity on each conductor and V the potential of the charge.

The paper then passes on to the case of the Mechanical Value of Magnetism. His reasoning is as follows:—Take a piece of iron, allow it to approach a magnet. The induced magnetism becomes greater as the iron gets nearer to the magnet. There is a certain amount of work done by the attraction during the approach. Now move the iron carefully from the magnet. The magnetism remains nearly constant, due to the coercive force of the iron. More work is done in the removal than on the approach. The balance is the mechanical value of the magnetism remaining. By a very subtle process of reasoning Kelvin deduced the total energy which would have to be expended on the magnetic material to set up a given magnetic condition, and he arrives at the result that if W is the total energy in a given volume of magnetic material, R the magnetic force, and $k$ the permeability, every element of volume contains energy proportionate to the square of the magnetic force and to the permeability and the total energy W,

$$W = \frac{1}{8\pi} \int\int\int dx\, dy\, dz\, (k)\, R^2.$$

*Energy of electric currents.*—As mentioned above, the part of the paper dealing with this subject as ultimately expanded in Nichol's Cyclopædia is worth setting out in full thus:—

"3. Electricity in Motion. If an electric current be excited in a conductor and then left without electromotive force, it retains energy to produce heat, light, and other kinds of mechanical effect, and it gradually falls in strength till it becomes insensible, as is amply demonstrated by the initial experiments of Faraday and Henry, on the spark which takes place when a galvanic circuit is opened at any point, and by those of Weber, Helmholtz and others on the electromagnetic effects of varying currents. Professor Thomson has shown how the mechanical value of all the effects that

* Appendix I.

a current in a closed circuit can produce after the electromotive force ceases may be ascertained by a determination, founded on the known laws of electrodynamic induction, of the mechanical value of the energy of a current of given strength circulating in a linear conductor (a bent wire for instance) of any form. To do this, it may be remarked, in the first place, that a current, once instituted in a conductor and circulating in it after the electromotive force ceases, does so just as if the electricity had inertia, and will diminish in strength according to the same, or nearly the same laws as a current of water or other fluid, once set in motion and left without moving force, in a pipe forming a closed circuit. But according to Faraday, who found that an electric circuit consisting of a wire doubled on itself, with the two parts close together, gives no sensible spark when suddenly opened, in comparison with that given by an equal length of wire bent into a coil, it appears that the effects of ordinary inertia do not exist for electricity in motion, or are but small compared with those which, in a suitable arrangement, are produced by ' the induction of the current itself.' In the present state of science it is only these effects that can be determined by a mathematical investigation, but the effects of electric inertia,* should it be found to exist, will be taken into account by adding a term of determinate form to the fully determined result of the present investigations, which expresses the mechanical value of a current in a linear conductor as far as it depends on the induction of a current upon itself.

" The general principle of the investigation is this : —That if two conductors, with a current sustained in each by a constant electromotive force be slowly moved toward one another, and there be a certain gain of work upon the whole, by electrodynamic force, operating during the motion, there will be twice as much as this of work spent by the electromotive forces (for instance, twice the equivalent of chemical action in the batteries should the electromotive forces be chemical) over and above that which they would have had to spend in the same time, merely to keep up the current, if the conductor had been at rest [because the electrodynamic induction produced by the motion will augment the currents].† While on the other hand if the motion becomes such as to require the expenditure of work against the electro-dynamic forces to produce it, there will be twice as much work saved off the action of the electromotive forces [by currents being diminished during the motion].† Hence the aggregate mechanical value of the currents in the two conductors, when brought to rest, will be increased in the one case by an amount equal to the work done by mutual electrodynamic forces in the motions, and will be diminished by the corresponding amount in the other case. The same considerations are applicable to relative motions of two portions of the same linear conductor (supposed perfectly flexible).

" Hence it is concluded that the mechanical value of a current of given strength in a linear conductor of any form is determined by calculating the amount of work against electro-dynamic forces required to double it upon itself, while a current of constant strength is sustained in it. The mathematical problem thus presented leads to an expression for the required mechanical value consisting of two factors, of which one is determined according to the form and dimensions of the line of the conductor in any case, irrespectively of its section, and the other is the square of the strength of the current. The mechanical value of a current in a closed circuit, determined on these principles, may be calculated by means of the following simple formula, not hitherto published,

$$\frac{1}{8\pi}\int\int\int \mathrm{R}^2\, dx\, dy\, dz,$$

where R denotes the resultant electromagnetic force at any point $(x\ y\ z)$.

" This expression is very useful in the dynamical theory of magnetic electric machines and electromagnetic engines. As an example, let the circuit consist of a length $l$ of wire wrapped in a helix approximating to a succession of circles on a cylinder of length $a$. The mechanical value of the current of strength $y$ flowing through it is approximately $\frac{1}{2}(l^2/a)\,y^2$, whatever be the diameter of the cylinder provided it is very small in proportion to its length. For instance, let 100 ft. of wire be wrapped on a cylinder an inch or two in diameter and one foot long. The mechanical value of a current of unit strength (or a current which would decompose about 1/50 of a grain of water per second) flowing through it, is 50,000 dynamical units. We must divide this by 32·2 to reduce to 'foot-grains' and we find therefore that the *vis viva* or 'actual energy' or mechanical value of the current in that case (which is just such as a very ordinary experimental illustration might be) is 1,550 times as much as is produced by gravity upon a grain of water descending through one foot. If we divide again this number by 1,390 to reduce to thermal units we find 1·12, and conclude that about a grain and a tenth of water would be raised in temperature one degree Cent. by the spark on breaking circuit, or that 1,600 such sparks would provide the same elevation of temperature to $\frac{1}{4}$ of a pound of water. It is well known that these effects are immensely increased by inserting soft iron into the cylindrical space surrounded by the coil. The same thing gives complete indication for finding *how much* (greater), when experimental determination of the law and amount of magnetization are complete enough to supply the requisite numerical data. The following definition is of importance in application of the theory of the energy of electricity in motion. The electro-dynamic capacity of a linear conductor of any form is double the mechanical value of a current of unit strength circulating in it."

It is exceedingly interesting, looking back over the 58 years which have elapsed since it was written, to notice one or two points. In particular may we observe the precision with which he reduced his mathematical results to a statement in terms of the heat equivalent, and the fact that at that date he was working primarily in dynamical units instead of, as most of his contemporaries did, in arbitrary units. Further, we may note

* Appendix *a*. † Appendix *b*.

that although he states that the energy is not the same as the energy of motion of something in the wire, he is careful to point out that a term may have to be added if it should be found that there is some motion in the wire. Our present electron theory of the electric current was thus provided for.

In the course of the article thus abstracted, we find he states, having referred to the formula he then gives for the energy in an electromagnetic field: "This expression is very useful in the dynamical theory of magneto electric machines and electromagnetic engines," meaning thereby what we should now call generators and motors. It is curious that neither he nor any other writer has, in fact, developed the theory of generators and motors on the basis he then proposed, and it is the purpose of this lecture to show how a general theory and classification of electric engines arises from the principles Kelvin enunciated.

### The Dynamical Theory of Electric Engines.

The history of science and engineering shows many instances of the advantages arising from viewing a subject from a new standpoint. There is, in fact, a tendency at all times for the standpoint to crystallize, and accordingly for progress more or less to stop; and a new standpoint may form a starting-point for new results, and it may be that to look on some problem with the eye of one of the founders of electric and magnetic science may form such a new starting-point.

Let us now briefly consider the ground which Kelvin traversed in his original paper and the subsequent additions, and endeavour to get a clear image of what he was defining.

*Electrified systems of conductors.*—Kelvin states in his paper that the energy stored or involved in any system of electrostatically charged conductors is perfectly defined and is stated as follows:—

The total energy is equal to half the sum of the products obtained by multiplying the quantity of electricity on each conductor into the potential within.*

In other words

$$\text{Energy} = \tfrac{1}{2} \Sigma (\text{Quantity} \times \text{potential}).$$

The seat of this energy lies, as has been shown by Faraday, Kelvin, and Maxwell, in the medium filling the space lying between the charged conductors, and although the statement above given holds good for all cases for a given geometrical arrangement of the conductors in a given medium, the relation between the quantity of electricity and the potential depends on the material between the conductors. It therefore follows that there are other definitions which may be useful in certain cases; and the energy stored in a system of charged conductors, as Kelvin himself in another place has stated, may be given in a different form, in the shape of an integral or summation including all the elements of the space forming the electrostatic field. Kelvin showed that in such a case for each element of space the energy is proportional to the square of the electrostatic force F multiplied by a constant K depending on the dielectric, and by a numerical factor, thus

$$\text{Energy} = \frac{1}{8\pi} \int\int\int F^2 K \, dx \, dy \, dz.$$

To see what is the maximum that any unit of volume, say a cubic centimetre, may contain of this stored energy, we may consider a simple case, say two greatly extended parallel plates charged to a difference of pressure so that the field of force is almost uniform between them. The space being filled with air for which K=1, the energy contained per cubic centimetre will be

$$W = \frac{F^2 K}{8\pi},$$

F being measured in electrostatic units. Taking the maximum grade of potential before the air breaks down to be 30,000 volts (about 100 electrostatic units) per centimetre, it follows that the maximum energy stored in the air space will be

$$W = 400 \text{ ergs per cubic centimetre.}$$

If instead of an air space we had had mica separating the plates, for which K the specific inductive capacity is 3 (air being taken as 1), then for the same difference of potential the energy would be 3 times as great, or 1,200 ergs per cubic centimetre; but as the breakdown stress in the case of mica is not reached until there is a potential grade of 1,000,000 volts per centimetre, we arrive at the result

$$W = 1{\cdot}3 \times 10^6 \text{ ergs per cubic centimetre (equal to about 1 foot-lb. per cubic inch).}$$

A system of conductors charged in this way and perfectly insulated will retain the energy for an indefinite time, but by bringing the conductors or wires connected with them sufficiently near, a spark will pass, or if they are connected by a conductor a current will ensue, and in either case the store of energy will be converted into heat.

The first formulæ given by Kelvin state the energy of the system of charged conductors with intervening dielectric in terms of the quantity of electricity and the potential difference, or alternatively in terms embodying the function named "capacity," which is the quantity of electricity contained in the system when charged to unit difference of potential. This quantity is the one which depends on the form, distances of the conductors, and nature of the dielectric, and is the physical quantity on which the energy relation of the system depends. By definition the capacity $C = Q/V$, so the stored electrical energy of the system may be expressed

$$W = \tfrac{1}{2} \Sigma (Q V) = \tfrac{1}{2} \Sigma Q^2/C = \tfrac{1}{2} \Sigma V^2 C.$$

In the first case the expression is the product of the electric quantity into the potential difference.

* In the mathematical theory of electricity the potential of a body is treated as an absolute quantity. In reality the absolute quantity is the difference of potential between this body and some other body, but in the mathematical method the second body is considered to be at zero potential, when the difference of potential and the absolute potential are the same.

In the second case the expression is in terms of the square of the electric quantity and the capacity.
In the third case the expression is in terms of the square of the potential difference and the capacity.

A consideration of these expressions leads to some important observations.

In text-books on Electrostatics we are told how conductors may be charged by contact with charged conductors, or by "induction." But the actions which take place from the energy point of view are not generally considered. In the case of a charged sphere so often cited in such works, it stands, say, in a room, the air of the room is the dielectric, every unit of the air space is the seat of strain energy, the walls, the floor, the ceiling are all being attracted to the sphere. We look upon the sphere as the charged body, but the inside surface of the room is also a charged body, and there is the same quantity of electricity on the surface of the room as on the sphere, so the only difference is that the energy being less concentrated at the surface of the room, effects are not easily observed there which are easily observed at the surface of the sphere. Now suppose we bring into the room another insulated sphere. The energy is stored in the dielectric; if the dielectric were replaced by a conductor the energy would disappear. Every part of the space which is occupied by a conductor involves a diminution of the volume of the dielectric and therefore some energy has been transformed, and the transformation is by mechanical work done on the second conductor, in other words it is drawn into the room. Now connect the second insulated sphere by a fine wire to the charged conducting sphere. Suppose they are the same size, and similarly placed in the room, the charge will now be distributed between the spheres. The capacity will be approximately doubled, the quantity of electricity remains the same, so the energy $Q^2/C$ becomes halved. Half the energy has appeared as heat in a spark and in heating the connecting wire as the current passes to charge the second sphere. If, instead of connecting the two spheres by a wire, the second sphere had been moved up to the first until it touched it, again the capacity would have been nearly doubled and the energy halved, but in this case part of the difference would have been transformed into mechanical work, the spheres being mutually attracted. In general, when an insulated conductor is charged by contact with a charged conductor, there is a loss of electrical energy in the electrified system, so that the ratio of the new energy value to the old value is the ratio of the old capacity to the new.

In the case of electrification by *induction* the phenomenon as described in the textbooks is thus:—An insulated conductor is brought near a charged conductor, the insulated conductor is connected to earth, the earth connection being removed the insulated conductor is found to have an electrical charge of opposite sign to that on the inducing body. But the operation is really this. The insulated conductor is in the electrostatic field, it lies between the two conductors forming the boundaries of the dielectric, it is connected to one of these conductors, *of which it becomes part*. This is equivalent to bringing the conductors of opposite electrification nearer to one another, consequently the *capacity is increased*, so the total energy decreases, and again we see that the charging of the conductor involves a decrease of energy. In this case also the difference is lost in the heat of a spark, or in the connecting wire. Consider the case of two flat plates A, B, and a third plate C half-way between them. The two plates, A, B, are charged with equal quantities of electricity on each, but of opposite sign. C is in the inductive field. We may connect it to A or B. It will take the charge of A or B as the case may be, and it will be clear that the so-called inductive charge is really a contact charge. Here again there will be a loss of energy as a spark or heat of wire. Suppose, however, C had been in contact with A, and then had moved to the centre, its final charge would be the same, the energy would be the same as in the case just described, but the electrical energy which has disappeared would have been given up as mechanical work done on the conductor during the motion. In general, therefore, electrification of an insulated conductor from a charged conductor results in a diminution of the electric energy of the system. And this diminution may be wasted as heat, or may be recovered as mechanical work.

A mechanical analogy may be given. Let A (Fig. 1) be a cistern full of water, B an empty cistern. The energy of the water in A relative to the floor of the cistern is $\frac{1}{2}h \times$ weight of water. Connect A to B by a pipe. The water will come to rest at a level in A and B,

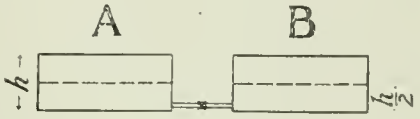



Fig. 1.

and if of equal volume the energy will be $\frac{1}{4}h \cdot w$. Half the energy will have disappeared as heat, in friction of the water in the pipe, or in friction of the water particles in B, till they come to rest. But we might have recovered the energy as mechanical work by a water motor in the connecting pipe.

To electrify an insulated conductor from a charged conductor, without loss of energy in heat, it must be brought into contact with the charging conductor in such a way that the capacity is unaltered, and then the capacity increased whilst the conductors are in contact, mechanical work being done by the electric forces. A general method is to bring the conductor to be charged inside the charging conductor without making contact, then make contact and maintain contact whilst the newly charged conductor is withdrawn.

*Magnetic matter.*—In the case of magnetized matter or a magnetic field, Kelvin states the value of the energy stored in the system in terms of the magnetic permeability and the magnetizing force existing, and he shows that the total energy may be expressed by taking the sum or integral of all the elements of volume, each multiplied by the square of the force existing

and by a constant depending on the magnetic permeability.

In this case if the magnetizing force is removed and the magnetism disappears, he states that the equivalent will appear as heat, but the case, as he himself points out, is complicated by the fact that magnetic materials are generally conductors, in which case part of the heat will be due not merely to a molecular re-arrangement, but to actual electric currents induced in the material. And as the method of removing the magnetic force, except in the case where this is due to electric currents, is difficult to define or foresee, it arises, as he himself has pointed out, that part of the energy may reappear in the shape of mechanical work done in removing the magnetizing forces. This is analogous to what has been stated as to electrical re-distributions.

The actual value given by Kelvin in his paper, using H instead of R, and $\mu$ instead of $k$,.

$$\text{Magnetic energy} = \frac{1}{8\pi}\int\int\int \mu\, H^2\, dx\, dy\, dz,$$

where $\mu$ is the permeability assumed constant and H the magnetic force.

If B is the induction, since $\mu H = B$, the above may be written

$$\frac{1}{8\pi}\int\int\int \frac{B^2}{\mu}\, dx\, dy\, dz.$$

The question of the actual values of the magnetic energy, and of the possible maximum, will be better considered under the next heading where the conditions are more defined.

*Conductors carrying electric currents.*—As has already been pointed out in the extract from the article in Nichol's Cyclopædia, Kelvin had defined quite clearly the value of the energy stored in a system of electric conductors carrying currents, and he had also remarked on the fact, quoting Faraday as his authority, that this energy was not located in the wire but in the space surrounding it. The expression which he gave in the article showed that the energy was a sum or integral arising in each element of volume, from the product of the square of the magnetizing force and the permeability of the medium; and he gives the case of a solenoid and calculates the value of the electro-dynamic energy in terms of the magnetizing force of the solenoid, acting on the space within it. It follows from the definition of electro-dynamic capacity, or as we now call it coefficient of self-induction, given in the last paragraph of the extract on "Electricity in Motion," that the energy of the single circuit system is

$$W = \tfrac{1}{2} L I^2,$$

where L is the coefficient of self-induction and I the current.

In the case of a system of more than one electric circuit the energy depends not only on the coefficients for each circuit multiplied by its own current squared, but on the products of the currents in the several circuits taken in pairs multiplied by a coefficient related to each pair. For two circuits

$$W = \tfrac{1}{2} L_a I_a^2 + M I_a I_b + \tfrac{1}{2} L_b I_b^2,$$

where $I_a$, $I_b$ are the currents for each circuit;

$L_a$, $L_b$ are the coefficients of self-induction for each circuit;

M is the coefficient of mutual induction between them.

These coefficients have been well called the energy coefficients of the electric circuit.

The maximum electromagnetic energy which may be stored in a unit space is not in this case limited as it was in the electrostatic case by any breakdown which will occur in the material forming the space. It depends entirely on the limitations involved by the heating of the conductor carrying the current producing the magnetic force. It is clear, therefore, that instantaneous values may be obtained of comparatively large dimensions. From a practical point of view, if we wish to obtain a maximum magnetic force in a given space, we adopt the system which has been used for the purpose of making experiments on the magnetic condition of materials under great magnetic forces, viz. by setting up the magnetic forces through a mass of iron which at some point in a nearly closed magnetic circuit is reduced in area so that the magnetic force is concentrated on a very small cross-section and length.

Professor Ewing in experiments on magnetic saturation working with the "Isthmus method" produced a magnetic force in the gap of H = 24,500. The energy in this case would be in air $24 \times 10^6$ ergs per cubic centimetre (equivalent to 32 ft.-lb. per cubic inch). If the gap was filled with soft iron with the same magnetic force, giving B = 45,350, the energy storage would be $44 \times 10^6$ ergs per cubic centimetre (53 ft.-lb. per cubic inch).*

It will be noted, therefore, that the storage of energy is not in itself of a very large magnitude. It is interesting to compare it with the amount of energy which can be stored in other ways by matter in a state of strain. For example, taking a very strong and rigid substance, the energy stored in steel piano wire when stressed to the breaking-point, which would amount to $1{\cdot}28 \times 10^3$ ergs per cubic centimetre (0·0017 ft.-lb. per cubic inch). Or again, taking a highly elastic substance, the energy stored in compressed air compressed in a cylinder from atmospheric pressure to 300 lb. per square inch without loss of heat (that is by adiabatic compression) would be $29 \times 10^6$ ergs per cubic centimetre (35 ft.-lb. per cubic inch).†

It is well to point out the difference in the storage of electromagnetic energy in air on the one hand, and highly magnetic material on the other. If we consider the relative amounts when the *magnetic induction* is the same, the storage in the case of air is greater

* Since this lecture was delivered an account has been published of experiments carried out by Professor Kammerlingh Onnes on the conductivity of metals at very low temperatures, in the course of which current densities of 1,000 amperes per square millimetre were obtained. Under these conditions the heating limit which is referred to in this lecture disappears and a magnetizing force in air of H = 100,000 was obtained. This would correspond to a storage of energy of $4 \times 10^8$ ergs per cubic centimetre (484 ft.-lb. per cubic inch).

† For examples of the storage of energy other than by strain, see C. P. Steinmetz: *General Electric Review* 1913, vol. 16, p. 536. Also Appendix 4.

than that in the case of iron, viz. in the inverse ratio of their permeabilities. So that for a moderate induction such as B=10,000, the energy in air being 1, that at low magnetizing forces, such as H = 5, the amount stored in iron is greater than that in air in the proportion of, say, 2,000 to 1, whilst if taken at the

(I)

TABLE SHOWING ENERGY RELATIONS OF ELECTRIC & MAGNETIC SYSTEMS

| NATURE OF SYSTEM | EXPRESSION IN TERMS OF ELECTRIFIED BODY, MAGNETIC MASS, OR CONDUCTOR CARRYING ELECTRIC CURRENT | EXPRESSION IN TERMS OF THE FORCES ON EACH UNIT OF SPACE | ACTUAL QUANTITIES WHICH MAY BE REACHED PER CUBIC CC. OF SPACE |
|---|---|---|---|
| Charged electric conductors<br>+ (QV) − (QV)<br>dx dy dz<br>F<br>(V) (V) | $\Sigma(QV)$ | $\frac{1}{8\pi}\iiint F^2 k\,dx\,dy\,dz$ | $4\times10^2$ ergs per c.c. in air at breakdown point<br>or<br>$1{\cdot}32\times10^6$ ergs per c.c. in mica at breakdown point |
| Magnetic matter<br>N S N S<br>dx dy dz<br>H<br>N S N S | | $\frac{1}{8\pi}\iiint \mu H^2 dx\,dy\,dz$ | $24\times10^6$ ergs per c.c. in air<br>$44\times10^6$ ergs per c.c. in iron |
| Conductors carrying electric currents<br>dx dy dz<br>I | For a single circuit $\frac{1}{2}LI^2$<br>For two circuits $\frac{1}{2}L_1I_1^2+MI_1I_2+\frac{1}{2}L_2I_2^2$ | In air $\frac{1}{8\pi}\iiint H^2 dx\,dy\,dz$<br>generally $\frac{1}{8\pi}\iiint \frac{B^2}{\mu} dx\,dy\,dz$ | As above |

in the same volume of iron will be 1/2,000; but if we consider the energy stored in the two cases when the *magnetizing forces* are the same, the result is quite different. In this case the energy stored is proportionate to the permeability; and consequently

point where the iron is practically saturated, the ratio is approximately 2 to 1.

It follows from this that if at any place where the magnetizing force is constant, we allow a piece of iron to replace a given volume of air a certain amount

of energy is converted into mechanical work, being the difference between the energy in the iron and the air. This amount of work divided by the distance the iron has moved to replace the air, gives the average force experienced by the iron in moving to the point in question. On this principle the attractive force of solenoids and electromagnets may be worked out in many instances.

In Table 1 will be found collected in tabular form the expressions derived by Kelvin in his original paper, with alternative expressions by himself and others for the energy in any electrical or magnetic system.

There are there shown the two distinct methods of exhibiting this energy, which have been very clearly distinguished by Maxwell: (*a*) that stated in reference to the actual electrified bodies or magnetic substance or the conductor carrying a current, and (*b*) that stated in reference to the space in which the energy is stored. These are illustrated diagrammatically in the first column and appear in the second and third columns respectively. The fourth column shows what this stored energy may amount to per cubic centimetre.

It is unnecessary here to consider the form in which the energy exists in the space comprised in electric and magnetic systems. Our knowledge as yet is not complete. We know that the electrostatic energy is in the form of a stress involving a tension in the direction of the force—and pressure at right angles thereto. The magnetic and electromagnetic energy is certainly kinetic; it also involves a tension along the line of the force and pressure at right angles thereto.

So far we have considered generally the statement as outlined by Kelvin relating to the energy stored in electrostatic and electromagnetic systems where the systems are fixed, and some of the results that arise, but Kelvin pointed out that electrified conductors and conductors carrying electric currents exert mutual forces, and if allowed to move will do mechanical work, or, if moved against the forces, will absorb mechanical work; *and he showed that these movements involved changes in the energy contained in the systems.* He also indicated that in all cases these energy changes are definitely related to the amount of mechanical work done or absorbed by the systems in moving, depending on the conditions under which the movement is conducted. By adopting the suggestions which he made in this direction we may show what are the definite relations between the mechanical work done and the changes in stored energy, and derive therefrom a complete dynamical theory of electric engines.

To commence with, it is necessary to give precision by a few definitions.

In the theory of the conversion of *Heat* into mechanical work, we are accustomed to speak of any mechanical apparatus for converting the molecular energy which we call Heat into mechanical work, or vice versa, as a *Heat engine*, and so we may define an *Electric engine* as any mechanism operating to convert electrical energy or electromagnetic energy into mechanical work, or vice versa. Again, in considering heat engines it is customary to deal with complete cycles, that is to say, the engine and the material which is being operated upon go through a certain series of movements and changes of conditions and finally return to the position and condition in which they started, and the consideration then turns upon the total energy put in as heat, and the energy given out by conversion from molecular to mechanical work. Such a cycle is conveniently divided into parts, and arising from the fact that all the original forms of heat engine were reciprocating engines, the parts may be divided into strokes, and in each stroke some definite operation takes place, under conditions which are devised for the purpose. The same procedure will be adopted here in the case of electric engines.

In the case of heat engines we consider an "ideal" engine, that is to say, one in which there are no losses from friction or leakage or heat transference in any way, except in the defined thermodynamic way which is under consideration. So also, in dealing with electric engines: they may be considered as "ideal" engines, having no friction, no loss from electrical leakage, and in the case of conductors carrying electric currents we shall assume they have no electrical resistance. The reasons for these assumptions in each case are that there is in principle no limit to the extent to which these extraneous losses of energy may be diminished, and the object of the investigation is to find out what is the "ideal" happening when these extraneous losses do not exist.

*Definition.*—The efficiency of an engine is the ratio, in a completed cycle, of the energy converted into mechanical work to the total energy supplied.

We may now proceed to consider electric engines.

## PART I.

### Electric Engines Converting Electric Energy into Mechanical Work.

*Electric engines.*—There are three groups of electric engines which may be considered:—

(A) Electrostatic engines where the forces producing motion are due to the mechanical attraction or repulsion between electrically charged conductors;
(B) Magnetic engines where the forces producing motion are those existing between magnetized bodies; and
(C) Electromagnetic engines where the forces producing motion are those set up by conductors carrying electric currents.

(A) *Electrostatic engines.*—If we consider that when electrically charged and insulated conductors move under the action of their mutually attractive or repulsive forces work is done, and that this energy is derived from the electrostatic energy of the system, we arrive at the conclusion that the factor determining the movement is the change in the electrostatic capacity thus brought about, and that any change of electrostatic capacity produced by a movement of the system will determine a transformation of electric into mechanical energy.

The capacity may be changed either by a movement of the conductors in a medium of constant specific inductive capacity, or by a movement of the conductors, relatively fixed, so that a medium of different specific inductive capacity lies between them. Thus considering two flat plates electrically charged they will move towards one another in air; but if at a fixed distance, a plate of mica or other substance of specific capacity higher than air will be drawn in between them.

So there are two fundamental types constructively :—

(1) Where charged conductors move relatively in a medium of uniform specific inductive capacity.
(2) Where charged conductors relatively fixed move in a medium of varying specific inductive capacity.

Further, in each case there are two cases which arise :—

(*a*) Where the conductors are charged and insulated and then move, that is, where the quantity of electricity is constant.
(*b*) Where the conductors are connected to a source of electrification and the potential difference is constant.

In the case of (*a*) it is clear that the work done in the movement (W) is the equivalent of the change of energy of the system, and that an increase of electric capacity diminishing the energy of the system corresponds to mechanical work being done.

In the case of (*b*) an increase of electric capacity also corresponds to mechanical work being done, but the potential difference being maintained constant an increase of capacity results in an increase of the electric charge Q; consequently electric energy is being supplied to the moving conductors. Kelvin showed that in this case the mechanical work done and the increase of electric energy are equal, so that the energy supplied to the system is twice the work done mechanically.*

So in the case (*a*) the mechanical work is equal to the decreased energy of the system; in (*b*) it is equal to the increased energy of the system.

Now let us apply these results to consider the efficiency of electric engines of the several types. A simple engine will consist of two plates, and the cycle will be as follows. The plates at a distance are charged, allowed to approach doing work, discharged, and moved apart doing no work.

We will call the potential difference $V_0$ and $V_1$, the capacity $C_0$ and $C_1$, the energy of the system $W_0$, $W_1$, at the beginning and end of the working stroke, and the mechanical work done $W_m$.

*Case* (*a*). The plates are charged.

The energy $$W_0 = \tfrac{1}{2} V_0^2 C_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The plates move to a position where $C_0$ becomes $C_1$. The energy becomes

$$W_1 = \tfrac{1}{2} V_1^2 C_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The mechanical work done is

$$W_m = W_1 - W_0 = \tfrac{1}{2} (V_0^2 C_0 - V_1^2 C_1) \quad . \quad . \quad . \quad (3)$$

* Appendix 5.

But the quantity of charge Q is constant, so VC is constant, hence $V_1^2 = V_0^2 C_0^2/C_1^2$, so (3) becomes

$$W_m = \tfrac{1}{2} (V_0^2 C_0 - V_0^2 C_0^2/C_1) = \tfrac{1}{2} V_0^2 C_0 \{1 - C_0/C_1\}.$$

The plates are now discharged, and moved back to the original position, no work being done, and the cycle is complete.

The efficiency

$$\eta = \frac{W_m}{W_0} = \frac{V_0^2 C_0 \{1 - C_0/C_1\}}{V_0^2 C_0} \quad \text{or} \quad 1 - \frac{C_0}{C_1}.$$

A quantity which approaches unity as the ratio of the initial capacity to the final capacity increases, it being, however, remarked that the work done depends on the magnitude of $C_0$, so that in practice the ratio must be increased by increasing $C_1$ not by diminishing $C_0$.

*Case* (*b*).—A similar method of dealing with this case is adopted.

The plates being charged. $W_0 = \tfrac{1}{2} V_0^2 C_0$.

The plates move, remaining in connection with a source of constant potential difference.

$$W_1 = \tfrac{1}{2} V_1^2 C_1.$$

The increase in energy is $W_0 - W_1$.

The electrical work supplied during the movement, $W_0 = 2 (W_1 - W_0)$.

As has already been given, the mechanical work done is $W_1 - W_0$, so finally the efficiency

$$\eta = \frac{W_1 - W_0}{2 W_1 - 2 W_0 + W_0} = \frac{C_1 - C_0}{2 C_1 - C_0},$$

a quantity which as $C_0$ diminishes to zero becomes $\tfrac{1}{2}$.

For given values of $C_0$ and $C_1$ the efficiency of type (*a*) is greater than type (*b*), but the mechanical work done, which in (*a*) is $\tfrac{1}{2} V_0^2 C_0 [(C_1 - C_0)/C_1]$, in (*b*) is $\tfrac{1}{2} V_0^2 (C_1 - C_0)$.

So that the mechanical work done by a given apparatus in the second case is greater than in the first case in the ratio of $C_1/C_0$. This might easily be 10 or 20 times as great.

The two working strokes of the cycles (*a*) and (*b*) may be combined and in this case the cycle would be as follows :—

(1) Plates in position of lowest capacity charged.
(2) Capacity increased whilst connected to source of constant potential difference, work being done mechanically and stored electrically.
(3) Supply disconnected and capacity further increased, mechanical work being done whilst energy stored is converted.
(4) Plates at position of maximum capacity discharged.
(5) Return stroke doing no mechanical work.

The efficiency of this cycle will depend on the point at which the energy supply ceases, and a general expression is too unwieldy to be interesting.

Without wishing to push the analogy too far, the

two cycles (*a*) and (*b*) may be compared with heat engines of certain types.

Case (*a*) corresponds to the case of a cylinder and piston where the piston, not quite at the end of the cylinder, has steam admitted behind it till the space is filled. The valve is now closed and the energy of the steam expanding drives the piston forward.

At the end of the stroke the steam is released and the remaining pressure energy lost.

Case (*b*) corresponds to the case of a cylinder with piston, where the steam is admitted at full pressure throughout the whole stroke. The work done is greater in this case, but as the steam finally exhausts at full pressure, the efficiency is lower.

The combined cycle last given compares with the case where steam is admitted through part of the stroke and then expanded and finally exhausted at a moderate pressure.

One more case will be examined. Assume the plates are charged by connection to a source of constant potential. They are allowed to approach, at some point the supply is disconnected, they approach further till the capacity has reached its maximum value and the difference of potential is small. Now, instead of discharging the plates, connect the moving plate to a conductor of large capacity at the same potential. Next move the plates apart; mechanical work will be expended in so doing, the potential will remain constant at the lower level, and the electrical charge will diminish. When it has diminished to the value it had when the plates were first charged, disconnect the plate from the large conductor and continue the motion, still doing work on the system. The potential will rise, and finally the end of the cycle will be reached with the potential and charge the same as at the beginning. A quantity of electricity taken in at pressure $V_0$ will have been given to the large conductor at pressure $V_1$ and the efficiency in this case will be

$$\eta = \frac{V_0 - V_1}{V_0}.$$

The difference between this case and the combined case previously given where the plates are finally discharged is that the energy transferred to the conductor of large capacity is still in an available form, and the original charge on the system remains, and might be made available in a manner which will later appear, whereas when the plates are discharged the whole remaining energy has been dissipated in heat, including the original charge.

This case is equivalent to the case of a heat engine which takes in heat at constant temperature expanding the gas isothermally, then the supply of heat being discontinued the gas expands adiabatically, converting the heat energy into mechanical work; compression isothermally at a lower temperature then follows absorbing mechanical work, and finally adiabatic compression brings the cycle to a close at the temperature and pressure first existing.

The pressure-volume diagram of such a cycle for a heat engine is given in Fig. 2, and the area enclosed by the curved lines represents the mechanical work done.

The electrical cases given may also be illustrated by diagrams. If we draw a diagram upon which the ordinates are one-half the squares of the potential difference and the abscissa the capacity, the product of the ordinate into the abscissa at any point will be $\frac{1}{2} V^2 C$, that is, the electrostatic energy. The rate of

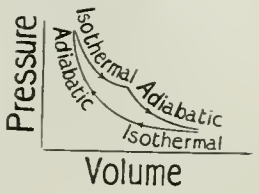



Fig. 2.

doing work mechanically as C varies is $d W = \frac{1}{2} V^2 d C$, and hence the mechanical work done $W = \frac{1}{2} \int V^2 d C$, that is, the area enclosed between the base, the first and last ordinate and the curved boundary.

On such a diagram case (*a*) would appear as in Fig. 3.

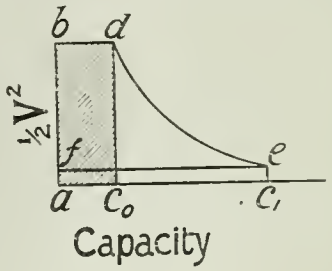



Fig. 3.

$a\,b$ represents $\frac{1}{2} V^2$ (one-half the square of the potential), $a\,c_0$ is the initial capacity, $a\,b \times a\,c_0$ (the shaded area) represents the energy originally put in electrically. If the capacity now increases, the square of the potential will follow the line $d\,e\,c_1$, and finally the energy left and lost in discharging the plates will be $e\,c_1\,a\,f$. The area enclosed between $c_0\,d$, $e\,c_1$, and the curved line is the energy converted into mechanical work.

Case (*b*) is shown in Fig. 4.

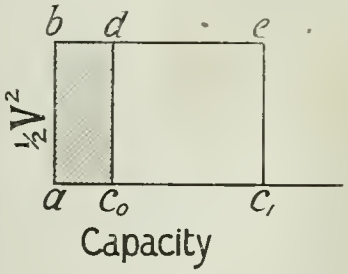



Fig. 4.

$a\,b\,d\,c_0$ is the energy of the initial charge, $d\,e\,c_1\,c_0$ is the mechanical work done at constant potential as the capacity increases, and is also the energy added to the system. On discharging the plates the total

energy $a\,b\,e\,c_1$ is all lost as heat. The combined cycle is therefore as shown in Fig. 5.

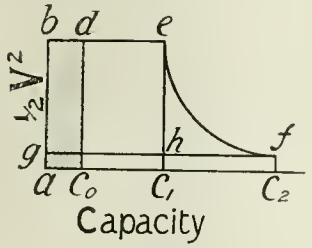



Fig. 5.

$a\,b\,d\,c_0$ is the energy of the initial charge, $c_0\,d\,e\,c_1$ is the mechanical work done at constant potential, and is also the electrical energy added to the system, $e\,f\,c_2\,c_1$ is the energy converted into mechanical work, $g\,f\,c_2\,a$ is the energy finally lost as heat. The last case described is illustrated in Fig. 6.

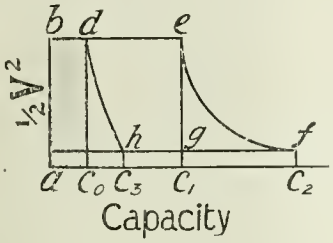



Fig. 6.

$a\,b\,d\,c_0$ is the energy of the initial charge, which in this case does not recur after the first cycle. $c_0\,d\,e\,c_1$ is the mechanical work done at constant potential, and also the energy added to the system, $e\,f\,c_2\,c_1$ is the energy converted into mechanical work. $f\,h\,c_3\,c_2$ is the electrical energy transferred from the system to the large conductor, and is also the mechanical work done on the system. $h\,d\,c_0\,c_3$ is the work done in raising the potential of the charge to the initial pressure.

These cases have been gone into at considerable length because they illustrate very fully the method of considering the actions and efficiencies of electric engines from a dynamical point of view, and because, also, although electrostatic motors have never been used in any practical way, it is possible that a study of them, particularly if the use of air as the dielectric medium were abandoned, might lead to practical results.

The actual efficiencies given are in all cases dependent on the energy being supplied, in such manner that the pressure and charge increase simultaneously, that is, that there is no loss on charging the system.

I have shown that in general there is such a loss, and this will correspondingly modify the efficiencies except in the last case.

The results have all been considered in relation to engines of type 1 (moving conductors), but the results apply equally to engines of type 2 (variable dielectric), and there is no need to consider these in detail.

We now pass to Class B.

(B) *Magnetic engines.*—In considering a magnetic engine we have to consider by what process, apart from electric currents, matter may be magnetized and demagnetized so as to give either a reciprocating or rotary effect.

The only process which I have ever seen discussed in this category is based upon the fact that iron at a certain temperature becomes non-magnetic. Thus a piece of iron placed in a magnetic field may be attracted or moved under magnetic forces, produced, say, by a permanent magnet, doing work in so moving; the iron then being heated, becomes demagnetized and may move back again to the original position without any work being done, and such a cycle would produce mechanical work. I know of no practical example of such an engine, and in any case the questions involved, such as the mode of the conversion of magnetic energy into heat or vice versa, are so complex and the factors so unknown that it would be pure speculation to attempt any investigation.

(C) *Electromagnetic engines.*—Before proceeding to consider in detail this, the most important section, it is necessary to clear our ideas by considering the properties of the electric circuit as it applies to the case of electric engines. We are accustomed to consider the relation defined by Ohm's law for steady currents as so fundamental, that we are apt to forget that this relation is almost unimportant in the case of electric engines in theory or even as they occur in practice, and as in the case of the "ideal engine" we shall, as we have already stated, consider the resistance of the circuit as zero, it is of no importance. The laws of the electric circuit with which we have to concern ourselves are the following:—

(*a*) That in any fixed closed electric circuit unless there is an electromotive force acting, the current once established by an E.M.F. will remain steady at the value at which it has been established.

(*b*) By movement of the circuit relative to other circuits or by change in the magnetic surroundings of the circuit there would be a tendency to change in the magnetic induction through the circuit, in which latter case the current will vary without any superposed E.M.F., so that the magnetic induction through every circuit remains constant. In this case the quantity known as the electro-kinetic momentum remains constant. For a single circuit the electro-kinetic momentum $K = L\,I$. For two circuits A and B the electro-kinetic momentum has the following form:—

For Circuit A $\quad K_a = L_a\,I_a + M\,I_b$,
For Circuit B $\quad K_b = L_a\,I_b + M\,I_a$.

It is necessary that these two conditions should be very clearly appreciated because on them pivots the whole examination of this type of engine.

We may also bring into view the generalization known as Lenz's law, which is as follows:—

*Lenz's law.*—In all cases of electromagnetic induction caused by mechanical movement, the induced currents have such a direction that their reaction tends to stop the motion producing them.

A consideration of the general expression for the forces acting between electric conductors carrying

currents makes it desirable to divide the subject into two sub-divisions, namely :—

(1) Engines of one electric circuit and variable coefficient of self-induction.

(2) Engines of two or more electric circuits with variable coefficient of mutual induction. (Two circuits will be here considered.)

(1) *Engines of one electric circuit and variable self-induction.*—To clear our ideas let us consider a simple case, viz. a solenoid with an iron core which may move in or out of the solenoid. There are broadly two possible conditions arising during the inward stroke. The first of these is that in which the core being in the extreme outward position a current is started in the coil by applying an E.M.F., in which case the current will rise at a definite rate.

Let E be the E.M.F., $L_0$ the initial value of the coefficient of self-induction, and I the current, then

$$\frac{dI}{dt}=\frac{E}{L_0}.$$

Assume this continues until some value for the current $I_0$ is reached. A force exists urging the core into the solenoid. An amount of energy has been stored in the system

$$W_0=\tfrac{1}{2}L_0 I_0^2.$$

The source of the E.M.F. is cut off, and the coil (of no resistance) is short-circuited. The current will remain steady. Now let the core move into the coil. The electro-kinetic momentum L I is constant. When the core has moved into the coil, the coefficient of self-induction being $L_1$, the energy is

$$W_1=\tfrac{1}{2}L_1 I_1^2.$$

The difference between the initial and final energy is the mechanical work done. On breaking the circuit this last quantity of energy will be spent in heat, and the core may be moved out without any work being done and the cycle completed. The mechanical work done, divided by the initial energy supplied, is the efficiency, and this becomes

$$\eta=\frac{W_0-W_1}{W_1}=\frac{L_0 I_0^2-L_1 I_1^2}{L_1 I_1^2}=\left(\frac{I_0-I_1}{I_1}\right)$$

and

$$I_0=\frac{K_0}{L_0}\,I_1=\frac{K_0}{L_1}$$

hence

$$\eta=\frac{(L_1-L_0)}{L_0}.$$

This may be illustrated by a diagram as in the case of the electrostatic engine, but in this case the ordinate will be $\frac{1}{2}I^2$ and the abscissa L.

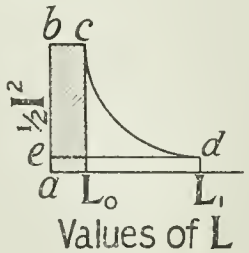



Fig. 7.

$a\,b\,c\,L_0$ is the initial electrical energy put in, $c\,d\,L_1\,L_0$ is the mechanical work done, $a\,L_1\,d\,c$ is the electrical energy finally lost in heat.

The second case (*b*) is that in which the current being established the core moves at such a velocity that the current remains constant. In this case the mechanical work done was shown by Kelvin to be equal to the energy added to the circuit, and the efficiency made be found to be

$$\eta=\frac{L_1-L_0}{2L_1-L_0}.$$

The diagram is shown in Fig. 8.

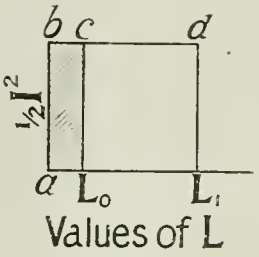



Fig. 8.

$a\,b\,c\,L_0$ is the initial energy, $c\,d\,L_1\,L_0$ is the energy added and mechanical work done, $a\,b\,d\,L_1$ is the energy lost on breaking the circuit.

There is an intermediate case of some theoretical interest. In the case (*a*) the mechanical work done during the stroke was equal to the decrease of electrical energy, in (*b*) it is equal to the increase of electrical energy. We may imagine the core to move at every point with such a velocity that the current squared diminishes as the value of L increases, so that the energy is constant. In this case the work put in electrically is equal at each instant to the work done mechanically.

The diagram is illustrated in Fig. 9

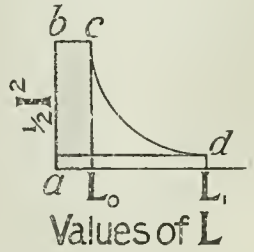



Fig. 9.

The curve *c d* is such that the product of ordinate and abscissa is at all points constant and equal to $a\,b\,c\,L_0$.

The efficiency in this case is*

$$\eta=\frac{\log_e(L_1/L_0)}{\log_e(L_1/L_0)+1}.$$

The next case is a combination of (*a*) and (*b*). That is the initial current is started, the plunger moves at

* Appendix 6.

constant current, then the supply is disconnected and the coil short-circuited and the core moves to its limiting position, when the circuit is opened and the remaining energy lost as heat.

The diagram is the full line part of Fig. 10.

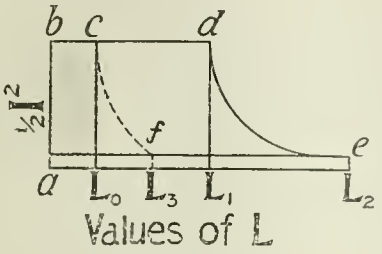



FIG. 10.

It will be unnecessary to go through this, and as there are a whole series of cases depending on the ratio of $L_0$, $L_1$ and $L_2$, the general expression for the efficiency is too complicated to be worth giving, but it can be worked out for any case.

The last case to be considered is similar to this, but at the point $L_2$ instead of the circuit being opened it is connected to a source of E.M.F. tending to stop the current. The current is, however, maintained constant by withdrawing the core at such a speed that on the diagram

$$\tfrac{1}{2} I_1^2 = e L_2,$$

mechanical work being done in withdrawing the core. The core having arrived at a position where

$$\frac{L_3}{L_0} = \frac{I_0}{I_1},$$

the core is withdrawn and the mechanical work done raises $\frac{1}{2} I^2$ to the original value, at the point $c$ in the diagram.

The net mechanical work done is equal to the area of diagram $c\ d\ e\ f$. The energy put in in each cycle $c\ d\ L_1\ L_0$.

An amount of energy equivalent to $e\ f\ L_3\ L_2$ has been transferred from the system to a circuit, and if this is the same circuit which supplied the original energy the efficiency $E = 1$.

This result is important. It shows that it is possible to make a motor with only one coil and with a moving iron core, with an efficiency of unity.

(2) *Engines of two circuits and variable coefficient of mutual induction.*—The class of engine we now have to consider is the class which from a practical point of view is the most important. In some ways it would have been best to have taken it first; on the other hand the ground we have gone over will lead up to the consideration of the more complex problems of engines of two circuits. For the purpose of the present exposition it will be assumed that, whatever relative movements the circuits go through, the coefficient of self-induction of the coils remains constant, but that the coefficient of mutual induction varies.

Whilst in the case of the electrostatic and the electromagnetic engines so far considered it has been simplest to take first the case of the establishment of the energy conditions, then the disconnection of the source, and to consider the movement of the parts under the action of the already stored energy, it will be best in the present case to take this later.

(*a*) *Engine of two circuits and working stroke of constant current (Electrodynamic stroke).*—We will therefore first consider the case of two coils of coefficient of self-induction $L_a$, $L_b$, currents $I_a$, $I_b$, and coefficient of mutual induction M. Connecting these to a source of E.M.F. with the coils parallel to each other and at some distance at which M is the value of $M_1$ the currents will rise and will reach values $I_a$, $I_b$.

The initial energy put into the system is

$$W_1 = \tfrac{1}{2} L_a I_a^2 + M_1 I_a I_b + \tfrac{1}{2} L_b I_b^2.$$

Suppose the currents are in the same direction, the coils attract one another. If they move with some particular velocity so that the E.M.F. induced by the motion balances that of the source, the current will remain constant. When some position is reached where M has the value $M_2$ the energy becomes

$$W_2 = \tfrac{1}{2} L_a I_a^2 + M_2 I_a I_b + \tfrac{1}{2} L_b I_b^2.$$

The difference is $W_2 - W_1 = (M_2 - M_1)(I_a I_b)$, the increase in electro-kinetic energy.

But, as Kelvin has shown, this is equal to the mechanical work done and the energy supplied is the sum of these two.

If we now break the circuits the energy disappears in a spark as heat and the coils may complete the cycle by moving back.

The efficiency $\eta = \dfrac{W_2 - W_1}{W_1 + 2(W_2 - W_1)}$, the maximum value of which is $\frac{1}{2}$.

The working stroke may be termed an electrodynamic stroke, since the work is being supplied by electrodynamic induction during the stroke.

(*b*) *Engine of two circuits with energy supplied before movement commences (Electro-kinetic stroke).*—The next cycle will be that in which the source of E.M.F. being connected to the coils the currents rise to values $I_{a1}$, $I_{b1}$. Then the source is cut off and both coils are short-circuited. As the coils approach, bearing in mind that the value of $L I_1 + M I_2$ will remain constant for each coil whilst M is increasing, it will be seen that the current in each coil and the total energy will decrease. But the important point to be considered is how will the current in each coil decrease. The author has been unable to find that any exposition has ever been given of the question of the variation of current and energy in two short-circuited coils when the coefficient of mutual induction varies. In the first case it is clear that if the coils are identical and the currents equal, the currents will vary equally. But suppose they are not identical or the currents equal, what will happen? The following is the investigation:—

*Variation of currents in two short-circuited coils moved so that* M *varies.*

From the equations

$$L_a I_a + M I_b = K \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$L_b I_b + M I_a = K_1 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

by substitution we have

$$I_a = \frac{L_b K - M K_1}{L_a L_b - M^2} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$I_b = \frac{L_a K_1 - M K}{L_a L_b - M^2} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From (1) and (2) we see that $M/L_a = K_1/K$ when $I_b$ becomes zero, and $M/L_b = K/K_1$ when $I_a$ becomes zero.

It follows that as M increases and the currents diminish, if in the case of either coil the ratio above given is reached, the current in that coil will become zero.

In other words the question is, as M increases will a value be reached in the coils where $M = (K/K_1) L_b$ or $M = (K_1/K) L_a$ respectively?

It is shown in the Appendix* that the greatest value of M is $\sqrt{(L_a L_b)}$.

Consequently

$I_a$ cannot become zero if $K/K_1$ is greater than

$$\frac{\sqrt{(L_a L_b)}}{L_b} = \frac{\sqrt{L_a}}{\sqrt{L_b}},$$

$I_b$ cannot become zero if $K_1/K$ is greater than

$$\frac{\sqrt{(L_a L_b)}}{L_a} = \frac{\sqrt{L_b}}{\sqrt{L_a}}$$

So the conditions for $I_a$ to become zero are that $M/L_b = K/K_1$, which involves that $L_a/L_b$ shall be greater than $(K/K_1)^2$.

Similarly for $I_b$ to become zero $M/L_b = K/K_1$ and $L_b/L_a$ shall be greater than $(K_1/K)^2$.

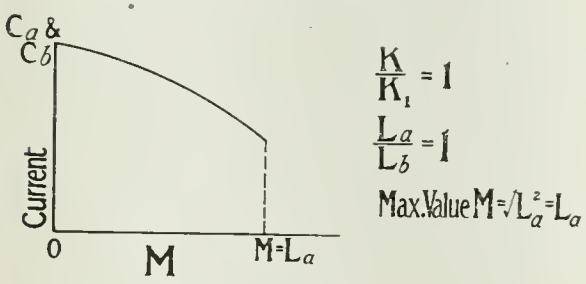



FIG. 11.

An investigation of the problem by means of a graphical method given in the Appendix† discloses the fact that in the case of unequal coils, that is coils in which the values of K, $K_1$, are not equal, and which satisfy the foregoing conditions, the current in the coil for which $K_1$ has the smaller value will diminish progressively as M increases, but the current in the coil with the larger value for $K_1$ will diminish at first and then increase till it attains the initial value when M is zero.

This may be illustrated by a few diagrams in which taking certain ratios of K, $K_1$, and $L_a$, $L_b$, we represent the values of $C_a$, $C_b$, as ordinates and M as the abscissa of a curve. On each diagram is marked the maximum value of M in terms of $L_a$, and also the value at which $L_b$ attains zero or the minimum value.

Having established the principle and the limits within which the current in one of the coils may be brought to zero, we may complete the consideration of the electro-kinetic cycle which was under review.

(*b*) *continued.*—We were considering the two equal coils with currents established the coils short-circuited and approaching. We now see that at the point of maximum value of M the currents may in the limit

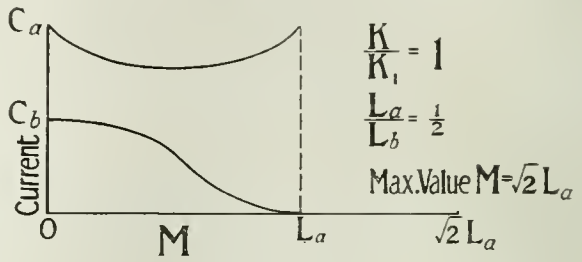



FIG. 12.

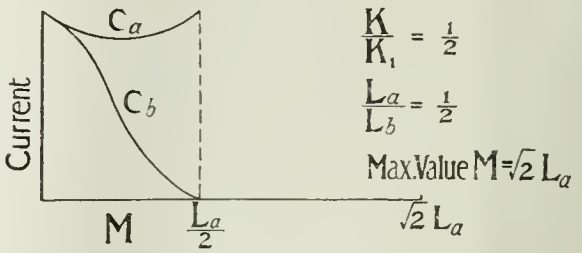



FIG. 13.

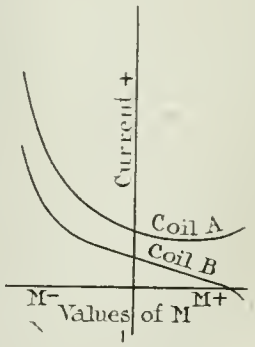



FIG. 14

be one-half the initial value. The energy is at the beginning

$$\tfrac{1}{2} L_a I_a^2 + \tfrac{1}{2} L_b I_b^2 = L_a I_a^2.$$

At the final position it is in the limit

$$\tfrac{1}{2} L_a I_{a_1}^2 + \tfrac{1}{2} L_b I_{b_1}^2 + M I_{a_1} I_{b_1},$$

that is $\tfrac{1}{2} L_a (\tfrac{1}{2} I_a)^2 + \tfrac{1}{2} L_a (\tfrac{1}{2} I_a)^2 + \sqrt{(L_a^2)}\, \tfrac{1}{4} I_a^2$

$$= \tfrac{1}{4} L_a I_a^2 + \tfrac{1}{4} L_a I_a^2 = \tfrac{1}{2} L_a I_a^2,$$

or one-half of the original energy; the difference is the mechanical work done.

* Appendix 7. † Appendix 8.

On breaking the circuits and moving the coils away without doing work the cycle is completed and the efficiency is

$$\eta = \frac{\frac{1}{2} L_a I_a^2}{L_a I_a^2} = \frac{1}{2}.$$

If when the coils were in the position of maximum energy the circuit of one only, say the B coil, had been broken, the energy instead of disappearing as heat would have been transferred to the A coil. The current therein would have been doubled, that is brought back to its initial value, and on moving the coils apart to a point when M=0 the energy remaining would be one-half of that originally put in, and the total efficiency would have been unity.

In general, if two short-circuited coils, A and B, are in a position where the mutual coefficient of induction is M, if the circuit of one of them, B, is broken there is a loss of energy represented by $W_b$

$$W_b = \frac{1}{2} I_b^2 \left( \frac{L_a L_b - M^2}{L_a} \right) *$$

As already stated the maximum value of $M^2$ when coils are geometrically coincident is $M^2 = L_a L_b$, in which case the loss will be zero. But for all cases the above expression will give the loss.

This expression is useful as showing the effect of short-circuited coils or amortisseurs.

We may now consider some cycles, in the case where the values of K, $K_1$ are unequal, and where the conditions satisfy the requirement for the current in one of the coils to become zero.

(*c*) Suppose the current is established in the A coil and that coil short-circuited; we may then establish a current in the B coil, the coefficient of mutual induction being zero. We may allow the coils to move till the current in the B coil is zero. The circuit being then opened the B coil is then removed doing no work. The current in the first coil remains at its initial value. The efficiency in this case is unity.

(*d*) Again, the current being established in the A coil this is short-circuited.

The current may be established in the B coil, this coil moves with constant current, and further energy put into the system, mechanical work being done. Then the B coil is short-circuited and moved till the current is zero, the circuit being opened and then moved away.

Again the current on the first coil completes the cycle at the same value as it commenced. Again the efficiency is unity.

(*e*) We may modify the cycle. The current being established in the A coil, the B coil is short-circuited and moved away. A current will be started and the coil may move, work being done on it till the energy and current are the same as in the first state of the previous example. The B coil is now connected to a source of current and the coils approach, the current in the B coil being maintained constant; finally the coil as before is short-circuited and the movement continued, and the whole energy of the system except the energy related to the circuit in the A coil will be recovered. Again the efficiency is unity.

This last case is the cycle of each coil of the ordinary closed-coil armature. There is also the case where the movement is such that the energy of the system is constant throughout the stroke, the current squared varying inversely as the value of M increases. The author has not fully investigated this case, but it may turn out to be the case in the unipolar or homopolar dynamo. It is not easy in these cases to represent either by diagram or formula the energy or current in each coil at all points except by the diagram in Appendix 8, but the fundamental fact lies in this, *that with one coil permanently short-circuited although the current and energy may vary*, it always *completes the cycle with the initial current and energy*—and with regard to the other coil *provided the current comes to zero when the circuit is opened the efficiency will always be unity.*

Now at this point it is useful to consider what is the relation between the engines and cycles we have been considering, that is ideal engines, and the engines which are practically realizable. In the first case we have assumed the coils to have no resistance. To what extent does this affect the problem. The error which arises is proportionate to the ratio of the loss of pressure due to ohmic resistance to the total E.M.F. acting in a coil due to electro-dynamic induction, in other words in an armature coil the ratio of the resistance loss of pressure to the total pressure. This will not be more than perhaps $1\frac{1}{2}$ to 2 per cent. In the same way the coil in which the circuit is not broken, the magnet coil as we call it. Here again the loss of pressure due to resistance, compared with the E.M.F. which would be set up if the changes took place at the periodicity of revolution of the armature, would give a very small ratio. It is true that the currents would not maintain themselves indefinitely in the actual coils of actual machines, but the decrements of current due to resistance in the time that the electromagnetic changes take place is so small as not to invalidate the process of reasoning which ignores them. It is well known, however, that the change of current in the permanently closed coil (magnet coil) of our ordinary types of motor and generator is small, and it may be argued from this that the foregoing reasoning is inapplicable.

The following explanation will show how this arises.

Let us suppose the coil A is the permanently closed coil and that the coil B is the moving coil connected

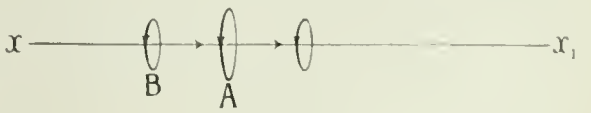



FIG. 15.

in turn to the source, and in turn short-circuited. Suppose it moves in a line $x\,x_1$ starting from a point $x$ where M=0. Let B be of such dimensions that it will pass through A. Then we may suppose the approach

* Appendix 9.

is made from $x$ to the coil $A_1$, then the coil passes through instead of being moved back. This is equivalent to moving it back Now the sum total of all the operations on B are such that finally $I_a$, the current in A, is the same at the end of a cycle as at the beginning.

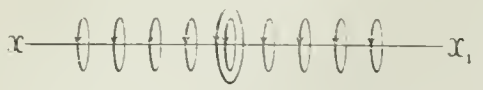



Fig. 16.

If now there were a series of coils all following one another as shown, all the operations are going on at the same time, with the result that the current in A remains steady.

This is what happens where, as in ordinary constructions, a series of coils follow one another. The first case is what happened in a type of machine little used nowadays, but of which something will be said later.

In motors as usually constructed we do not use coils approaching and receding in the way that the author has herein described. The two coils have a common axis about which one rotates lying in a plane which is at right angles to the plane containing the coils.

Thus in Fig. 17 if A B are two coils lying in one plane, $x\,x$ their central axis at right angles to the plane containing them, then the B coil rotates about an axis $y\,y$ lying in the coil plane.

In the position shown the coefficient of mutual induction is M. If the B coil moves through 90° the value of M becomes zero. If the B coil moves a further 90° M = −M. Fig. 14 shows how the currents change in such a pair of coils for the case where $K = K_1$, $2\,L_a = L_b$, $C_a = 2\,C_b$, and assuming $M = 0{\cdot}75\sqrt{(L_a\,L_b)}$. It is noted that when $M = 0$, $C_a = 2\,C_b$. At maximum positive value of M, $C_b$ is negative. $C_a$ has fallen and then risen. For negative values of M both currents rise to large values. In moving from M negative to positive values mechanical work is done; in moving from M positive to negative values mechanical work must be done on the circuit. The possibility of making engines of two circuits with efficiency = 1 turns entirely on the fact that one of the currents is thus brought to zero value.

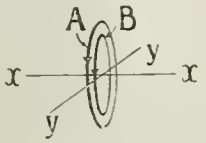



Fig. 17.

In other types (multipolar) the coils move across the face of the fixed coils, and the value of M varies from zero to M to zero and − M.

These constructional variations do not affect the principles arrived at.

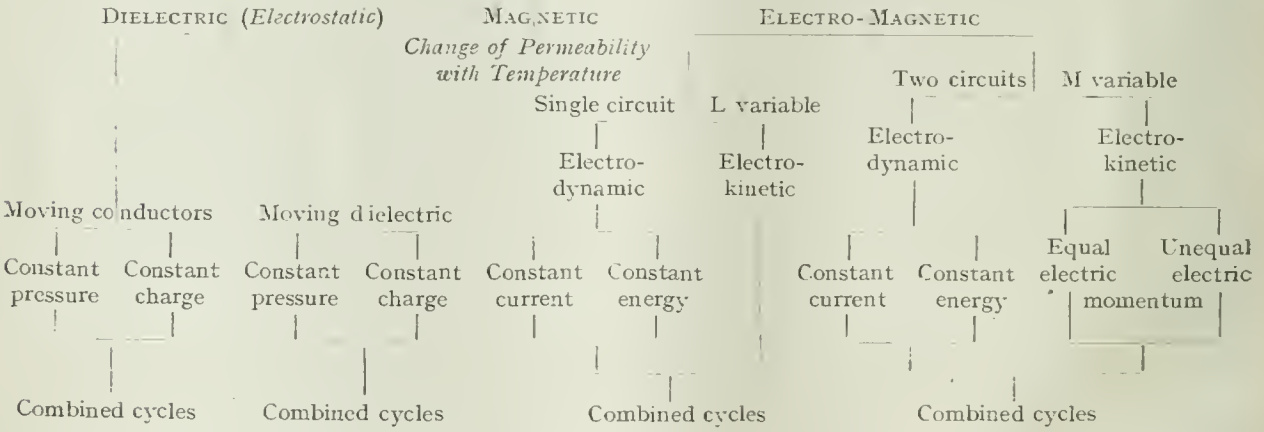
In the case of the coils as shown in Fig. 17, it is useful to trace out the particular cycle (*e*) which it has been stated above is the cycle of the closed-coil armature machine. Starting with the coils in the same plane [see Fig. 18 (1)] and with current in B=0, the coil B is short-circuited. It moves in the direction of rotation shown until at some position (2) the current in B is $C_b$. Mechanical work is done in moving it. The coil then comes into circuit with the other coils and the current is maintained constant by the external electromotive force till some position (3) is reached. The coil is short-circuited and moves finally to (4) where the current in *b* is again zero.

If there were only one coil B then the current in A

Table II.

*Diagram showing the Possible Primary Types of Electric Engine.*

ELECTRIC ENGINES



would go through the fluctuation shown in Figs. 11, 12, and 13. But if, as in the actual construction, there are a number of coils, then, the actions being superimposed as described and illustrated by Figs. 15 and 16, the current in A is appreciably steady. Nevertheless it is actually the short-circuited coil of this reasoning. The current actually has to be maintained

TABLE III.

*Summary of Types of Engines and Ideal Efficiencies.*

| Type of Engine | Type of Stroke | Efficiency of Ideal Engine | Limit |
|---|---|---|---|
| A. Electrostatic engines | | | |
| (1) Change of position of conductors | Electrostatic | $\frac{t-t_1}{t}$ | 1 |
| | Electro-dynamic | $\frac{C_2-C_1}{2C_2-C_1}$ | $\frac{1}{2}$ |
| (2) Change of dielectric between conductors | Electrostatic | $\frac{K_2-K_1}{K_2}$ | $\frac{4}{5}$ {Mica & air} |
| | Electro-dynamic | $\frac{C_2-C_1}{2C_2-C_1}$ | $\frac{1}{2}$ |
| B. Magnetic engines | — | — | — |
| C. Electromagnetic engines | | | |
| (1) Engines of one circuit Variation of L | Electro-kinetic | $\frac{L_1-L_0}{L_1}$ | 1 |
| | Electro-dynamic Constant current | $\frac{L_1-L_0}{2L_1-L_0}$ | $\frac{1}{2}$ |
| | Constant energy | $\frac{\text{Log}_e \frac{L_1}{L_0}}{\text{Log}_e \frac{L_1}{L_0}+1}$ | 1 |
| | A combined cycle | — | 1 |
| (2) Engines of two circuits Variation of M | Electro-dynamic Constant current | $\frac{W_2-W_1}{W_1-2(W_2-W_1)}$ | $\frac{1}{2}$ |
| | Electro-kinetic Case of equal circuits | $\frac{W_1-W_2}{W_1}$ | $\frac{1}{2}$ |
| | Case of unequal circuits | — | 1 |
| | $\frac{L_a}{L_b}$ greater than $\frac{K}{K_1}$ | | |
| | Combined cycles | — | 1 |

against a resistance, so an electromotive force is necessary, but electro-dynamically no electromotive force is necessary in this circuit.

Table II shows in diagrammatic form the primary types of electric engines, and Table III summarizes these and their efficiencies. The limiting efficiency in Table III, last column, is the efficiency beyond which no constructional improvement can carry the type, and does not mean that every construction of that type need have the efficiency given.

At this point we may summarize what has been shown.

It has been shown that in the case of electromagnetic engines there are two main divisions: (1) Engines of one circuit and variable self-induction, and that there is in general a low efficiency with this class, but at least one cycle with a possible efficiency of unity. (2) Engines of two circuits and variable mutual induction with a number of cycles, several of which can have an ideal efficiency of unity. The author ventures to suggest that some of these cycles merit more attention than they have received. The closed coil machine invented by Paccinotti and re-invented by Gramme gives one of these cycles, and it is probable that the fact that this construction gave a cycle of which the possible efficiency is unity is the cause why it was then and has been ever

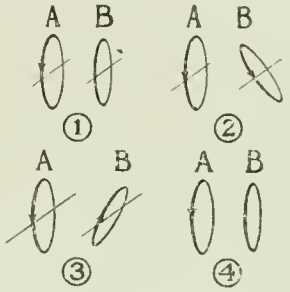



FIG. 18.

since adopted as practically the only cycle. The author thinks that if the principles of the cycles are more fully understood there is room for progress to be made for special purposes by adopting some of them. For example, the problem of a motor to run at a large range of speeds has with present designs been only partially met. Now consider what would occur if the cycle were adopted where the energy is put into the coil in the first position and then the coil at once short-circuited. The work done would depend on the energy put in; this would depend on how long the coil were connected to the supply circuit. Brushes could be arranged which would connect each coil for a longer or shorter period to the supply, and so at any speed any required amount of energy could be supplied. The open-coil type of machine, such as those of Brush, Thomson-Houston, and the semi-open coil Immisch machine, all gave very excellent results. But the two former as generators only—and we have seen the cycle on which they worked could not give as high efficiency as a motor, but by modification in accordance with the foregoing they could be made to do so.

## PART II.

### ENGINES CONVERTING MECHANICAL WORK INTO ELECTRICAL ENERGY.

*Electric generators.*—The fact that electric and electromagnetic conditions give rise to systems of parts moving under mechanical forces, and thus providing

motive power engines, naturally leads to the consideration of these types in the first instance as has now been done. But, as was shown by Faraday, these actions are reversible; indeed we have already had to deal with some strokes in which mechanical work was converted into electric energy. In considering electric generators it will be well to consider first what we really mean by an electric generator. When we speak of electric generators we do not really mean a machine which produces electrons, we mean one of two things: (*a*) An engine which by separating electrons from their associated atoms sets up a strain in a dielectric medium across or into which the electrons are pressing; this is the so-called electrostatic generator; or (*b*) a machine which, setting electrons in motion in a conductor, causes stresses in the space surrounding the wire due to a phenomenon of rotational movement in the ether; this is the electromagnetic generator. In either case the mechanical work done is converted wholly or in part, in the (*a*) case into stress-strain energy of the dielectric medium, in the (*b*) case into electro-kinetic energy of the ether.

*Electrostatic generators.*—The first and oldest type is the so-called frictional machine. We know with certainty comparatively little of its action. Two non-conductors or dielectric materials are brought into contact and then moved apart; they become oppositely electrified, that is, between them is a space in a state of strain. It is true these non-conductors are rubbed across one another under considerable pressure and friction, whence the name of the machine, but whether the friction is really a necessary feature is not known. If contact of dissimilar materials is the cause of the electrification, it would appear that a rolling contact would be equally effective. At all events it seems likely that the pressure has a function, in bringing materials not only into contact, but in providing that the parts by being very close form a series of condensers of very large capacity so that the maximum electrification per unit of area results. The parts are then drawn away from one another by doing mechanical work, the difference of potential increasing with the distance.

Apart from friction the operations are as follows:—The non-conducting substances come into contact. The electric displacement must arise from energy already stored in the materials in some prior stage of their chemical upbuilding. This amount of energy is lost in the sense that it is non-recurring; we cannot put it back. It is a very small part of the total energy of the electrification produced by the engine. The parts being thus in a condition that separation across a dielectric will stress the dielectric, the non-conducting surfaces are moved apart, mechanical work being done; and eventually the stress is diverted so that the stressed space is between certain conducting parts of the machine, the stress presently resulting in a breakdown of the dielectric in the form of a spark. The energy originally put in by the chemical or physical difference of the surfaces, once in the electrical form, is in the form of an electric charge, or $W_0 = \frac{1}{2} Q^2/C$. C is probably very large. When moved apart it becomes $W_1 = \frac{1}{2} Q^2/C_1$. So far the capacity is diminishing and the difference of potential rising.

To transfer the energy to the conductors of the machine the capacity of the conductor system must be greater than that of the plate and rubber system—so, as has already been shown, some loss of energy results. And in the actual machine a brush discharge over an air space certainly dissipates a further part of the energy as heat; but at all events were it not for the rubbing friction which is possibly, but not certainly, unnecessary, the cycle in itself would give a high efficiency. The one distinguishing feature of this type is the electrification by contact of *dissimilar dielectrics*. The next type of electrostatic generator depends on the production of an initial difference of potential by the contact of *dissimilar conductors*. On these being separated an electrostatic field is set up between them. This initial store of energy forms the base on which the operations proceed.

As the question of the electrostatic generating machine is wrapped in a good deal of confusion, it will be well to go simply and precisely through the operations on which they depend. Suppose A and B are two plates of zinc and copper respectively and that they are brought into intimate contact, we know that there will be a potential difference between them of nearly 1 volt. Let the contact be just broken; that is, the plates are separated by a very small layer of dielectric. If the area is *a*, and the average thickness of the dielectric *t*, neglecting the effect of the edges they will form a condenser of capacity C, where $C = K a/(4 \pi t)$, and a quantity of electricity will be on the plates, viz. $Q = C V$, and the energy in the intervening space is $W = \frac{1}{2} Q V = 2 \pi Q^2 t/(K a)$. The plates are now moved apart. Still neglecting the effect of the edges the energy will be directly on the distance between the plates, which simply means that the state of strain of the intervening dielectric is the same for every unit of volume, and as we increase the volume between the plates so the energy increases, being the equivalent of the mechanical work done in separation. Here, then, is the first step in electrostatic generation, the indefinite increase of electrostatic strain energy by doing mechanical work. But more is wanted. We want to increase the energy per unit of volume, or the intensity of the strain energy. The process adopted is as follows:—

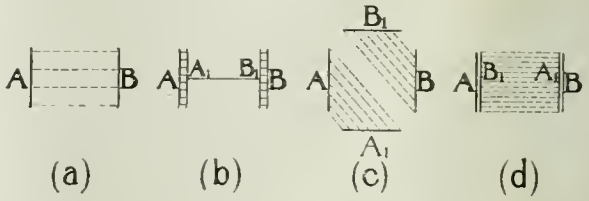



FIG. 19

In Fig. 19 (*a*) A, B are the plates with the electrostatic field intervening, the capacity being C.

In (*b*) the plates $A_1$ $B_1$ have been brought in between and metallically connected. The strain energy between

$A_1 B_1$ has been lost in heat and only that part between A $A_1$ and B $B_1$ remains. The capacities A $A_1$, B $B_1$ are each $C_1$. Disconnect $A_1 B_1$. Now move $A_1 B_1$ to the positions shown (*c*). There is some position where the total energy between A $A_1$ and also that between B $B_1$ are the same as the original totals between A B.

Now move $B_1 A_1$ respectively to where $A_1 B_1$ started, as in (*d*). The two fields are superimposed and the stress doubled and the strain energy per unit of space is quadrupled, being proportional to the square of the stress. By repeating the operation the strain energy may be increased to the ultimate limit of the electric strength of the dielectric.

The efficiency of the cycle may be shown to be

$$\eta = \frac{4\,C_1}{5\,C_1 - 2\,C}$$

If $C_1 = 2\,C$ this becomes unity. That is, assuming the capacity to be proportional to the distance between A B, $A_1 B_1$ are at the centre of A B when first put into contact, as in that case the energy of the original field remains.

A machine or engine working on this cycle will charge the two original conductors to a gradually increasing potential, or if there is a steady passage of electricity from A to B, will maintain a constant potential. As for most purposes electrostatic machines are used to give a spark, in other words, suddenly to liberate all the strain energy, it is convenient to charge independent conductors so that on discharge of these the strain energy in the original field remains. There are two ways of doing this. One is (referring to Fig. 19) to place conductors at points corresponding to the position of $A_1 B_1$ in (*c*); the other is to charge conductors from A B through some form of valve which allows a charge to pass when the potential difference exceeds a certain amount, and not otherwise, that is, an air-gap with or without point dischargers.

The practical realization of such a cycle would be as shown diagrammatically in Fig. 20. A B are the exciting or inducing plates. $A_1 B_1$ are the carrier plates, on arms revolving about C. *a b* are the collector plates nearer to the centre C than $A_1 B_1$. B *b* and A *a* are connected in pairs either directly or through discharging points.

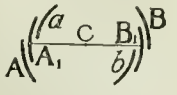



Fig. 20.

When $A_1 B_1$ are covered by *a b* they are connected to them by contacts or brushes, in which case the stress between them becomes a stress between *a b*, $A_1 B_1$ being as we should say discharged. This involves a loss of energy. This may be avoided by making the contact at some point before $A_1 B_1$ are completely covered by *a b*. As $A_1 B_1$ emerge from *a b* they are disconnected therefrom and connected by brushes to one another. In this way the decrease in energy between $A_1 B_1$ which we have already seen takes place, and is there shown as a loss in heat, is transferred into mechanical work and so is not lost.

It is on the principles thus developed that the original electrophorus of Volta, the so-called induction machines of Varley, Kelvin, Holtz, and Wimshurst operate. In the electrophorus the original electrification is set up by contact or friction of dielectrics: in the machines of Varley and Kelvin, by an initial charge from a battery or a dielectric; in that of Wimshurst by contact of dissimilar conductors. The conditions in none of these machines allow an ideal efficiency. The efficiencies and output are deplorably low. A Holtz machine with 10-in. plates driven at 600 revolutions a minute appears to have an output of 1 watt, and at a rough guess takes 25 watts to drive it. There is great scope for study and improvement, which can only be realized by a study of the cycles and their relative efficiency.

### Electromagnetic Engines Converting Mechanical Energy into Electrical Current Energy.

*Engines of one circuit and variable coefficient of self-induction.*—The first class of engines we considered in the category for converting electromagnetic energy into mechanical work—that is, engines of one circuit with variable self-induction does not now appear. In fact, this type of engine is not reversible. The reason is as follows:—To convert electrical energy into mechanical energy, or vice versa, we must commence with a store or supply of electric energy. It is not possible to start with a system, with electrons in equilibrium, and without any general drift or positive direction, and proceed therewith and therefrom to produce electrical or magnetic charges. Just as the electrostatic generator requires an initial store of energy, provided by atomic differences, so the electromagnetic generator must fall back on some store of electromagnetic energy.

*Engines of two circuits and variable coefficient of mutual induction.*—The simplest stroke and cycle in this type is that where, a current $I_a$ having been started in one coil A, the coil is short-circuited. Another coil B in some position where M is a maximum is moved by mechanical forces to a position where $M_1$ is less than M, being short-circuited. In so doing a current ($I_b$) is set up, after which the coil is connected to an external circuit. Let us suppose the current in B maintained at some value $I_b$. In this operation, as we have already seen, the mechanical work done is effecting two things. First, diminishing the electromagnetic energy of the system; second, converting the mechanical work done into electric energy. These two parts, as Kelvin showed, are equal. Now let the motion stop. The electromagnetic energy of the system will continue to diminish, and the current $I_b$ will diminish, till presently $I_b = 0$. At this moment $I_a$ has its initial value. On working through the steps of this cycle the ideal efficiency will be found to be unity. If we take any other cycle we can always allow the current in coil B to reach zero value; in other words, all cycles in this class of engine can have an efficiency of unity. This is a very important result.

It shows that there is a real difference between the principles involved in the conversion of mechanical into electrical or electrical into mechanical energy. This difference arises from the fact that in the latter case the total stored energy can only be converted into mechanical work by an indefinite increase of the coefficients of self or mutual induction or by some particular proportions between them, whilst in the first case the stored energy can always be converted into electrical work by the system being connected to a circuit containing an E.M.F. or its equivalent.

## PART III.

### Combined Generator and Motor Cycles.

So far we have considered independently the conversion of electrical energy into mechanical energy, and mechanical energy into electrical energy. But it is of interest to consider briefly a few cases where the conversion is accompanied by a reconversion. The transmission of power is one of the chief functions of electrical engineering, and in this operation the two processes are always combined.

A very simple case will illustrate how this may apply in the case of electrostatic conversion.

Let A, B (Fig. 21) be a pair of charged and insulated plates, and $A_1$, $B_1$ a similar pair, A being connected to $A_1$ and B to $B_1$.

Fig. 21.

If now A, B be separated by doing mechanical work on the pair, the difference of potential between $A_1$ and $B_1$ will rise, the stress between them increase, and work may be done by their approach. On A, B again approaching, some mechanical work will be done, but less than on their separation, and $A_1$ $B_1$ may now move apart, less work being required to move them apart than they performed in approaching.

So in each such cycle an excess of mechanical work will have been done on A, B, and an excess of mechanical work performed by $A_1$ $B_1$. As the whole of the energy charges have been effected by exchanges of mechanical work for electrical energy, and vice versa, the efficiency is unity.

In the corresponding electro-dynamic case A $A_1$ and

Fig. 22.

B $B_1$ are two pairs of coils short-circuited, with currents established, connected so that the currents circulate symmetrically.

Assume a current in B $B_1$, $I_1$. The coil B moves from A, mechanical work being done in moving it. $B_1$ moves towards $A_1$ doing mechanical work. The mechanical work done by $B_1$ is the same as the mechanical work done on B, and at the same time the electro-kinetic energy of the B system has been diminished and that of the $B_1$ system increased by equivalent amounts.

Let $B_1$ move further, and the current will diminish to $I_2$, electro-kinetic energy being converted into further mechanical work. Now let B approach A and $B_1$ move from $A_1$. Work is again transferred, but, the currents being less, the energy returned is less; finally B moves from A increasing the current to $I_1$. The efficiency of the cycle is unity.

In the extreme case the currents instead of being diminished on the return stroke might be reversed, and then we have the case of the alternator and synchronous motor.

Other such combined cycles may be arranged, but in all cases the ideal efficiency is unity.

In either case it is essential to the cycle, that to transfer energy from one system to the other, the movements should not be identical in time but the generator movement should precede the motor movement. If the movements are in phase energy will be transferred from one system to the other, but no mechanical work will be done or absorbed in a cycle.

Summing up, it will be seen in all the cases of motors and generators that the conversion of electrical into mechanical energy and vice versa arise when energy is put into the dielectric or the magnetic medium and taken out again. Consequently we should expect broadly to find that the size of apparatus necessary would follow the capacity as a container of energy of the medium in question. From this point of view we should expect to find that electromagnetic apparatus composed of air and iron whose capacity may be taken at $30 \times 10^6$ ergs per cubic centimetre must compare favourably with dielectric apparatus using air as the dielectric whose capacity is only a few hundred ergs per cubic centimetre, or even with a dielectric such as mica when it is about 1/40 that of iron. And experience so far bears this out. But there are reasons why with dielectric apparatus the number of changes of state per second might be much greater than with iron, and so in a large measure compensate for the divergence.

### Conclusion.

It would be possible to extend greatly the number of cases and examples which might be brought under review from the point of view of the transformation of energy from electric to mechanical, and vice versa, with the space energy as the intermediate receptacle and source. Thus alternating-current motors, whether induction type or synchronous, and generators of these types also might be considered. But whilst this would be carrying out what it is partly the object of this lecture, viz. to stimulate investigation of problems from a new view point, it would for the moment obscure the point which the author desires to put forward.

We may briefly review what ground has been covered. It has been shown that starting from the Kelvin original discovery and statement of the energy relations of the

electrical and electromagnetic quantities of any electric system, we may classify electric engines by the changes taking place in the energy put into such systems or taken out, electrically or mechanically. We have seen that we can then arrive at the ideal or possible efficiency of electric engines of various types. In passing, one cannot help being struck with the similarity in the form of the expressions for the efficiencies of ideal electric engines with the general form of the expression for the efficiency of a perfect heat engine, that is, the ratio of the difference between the temperatures of taking in and rejecting heat divided by the temperature of taking in heat $(t - t_1)/t$. The essential difference, however, lies in this. In the heat engine we can obtain an ideal efficiency of unity only if the temperature of heat rejection is zero on the absolute scale. That is if the substance used in the engine could be in such a state that the molecular motion we call heat had ceased. In the electric engines we can, in theory at least, reduce the final strain energy of the electrostatic engine, or the motion energy of the electromagnetic engine to zero, and so arises the much higher efficiency of electric engines. And this seems to arise from the fact that these electrical forms of energy have definite direction, they are not like heat energy which is directionless. We are, as it were, in the latter case dealing with the energy of a stream or a tide, in the former with the energy of the waves on the top of the sea, ever changing in direction and intensity. The general types and cycles of electric engines have been classified and considered and their efficiencies set forth. And thus those words of Kelvin quoted at the beginning, where he says the expression for the energy of an electromagnetic system may be very useful in the theory of electric engines, have been justified. But the author hopes that this lecture may have some further use. The author has spoken of the advantage of a new view point, in stimulating thought and invention. It took something like 2,000 years to come from the original steam jet engine of Hero to the Parsons turbine. It may be that some of the early and simple types of electric motor may be revived in a much shorter time if the principles and reasons of their inefficiency are grasped. There is every reason why rotating machinery should be driven through belts or gears from rotating electric motors, there is no good reason why the brake air pumps on an electric train should not be driven by direct reciprocating motors.* We have considered that next to defeating the German armies the production in our own country of a magneto for petrol engine ignition has been the most remarkable achievement of the war. The possibility is that one tithe of the energy devoted to this reproduction might have developed an influence electrostatic generator for the purpose, of much simpler and cheaper construction. In any case the use of electrostatic generators for some purposes would rapidly follow were they constructed of reasonable efficiency and moderate compactness. The younger members of this Institution may well look into some of these questions. There are wide fields for new designs and experiments, and it is possible that the thought of the energy aspect which Kelvin put before us will prove to be fruitful of new departures. It is because the author thinks this aspect has been overlooked that he has ventured to go over ground that may have been already traversed by some of his hearers, but which was never apart from the thoughts and ideas of the great discoverer of whom we remind ourselves to-night.

* To realize some of the cycles described requires the solution of some questions, notably the putting a coil out of circuit at the moment the current is zero. Some form of electrical non-return valve of higher efficiency than the aluminium valve has to be contrived.

## APPENDIX 1.

The mechanical value of the electrification is stated in this passage (page 2) as being equal to half the square of the quantity of electricity multiplied by the capacity. The word *multiplied* should read *divided*.

## APPENDIX 2.

What Kelvin here (page 3) had in his mind was the fact that if it should turn out that electricity was a substance, and an electric current was the movement of this substance in the wire, then there must be a term involving one-half the mass multiplied by the square of the velocity of the substance. Both Maxwell and Lodge have experimentally endeavoured to determine whether any such term exists, but so far without result. On the electron theory such a result is to be looked for. As to its probable amount, we may proceed thus on the assumption that the current consists in the motion of free electrons only. The mass of an electron $m$ is $0{\cdot}61 \times 10^{-27}$ grammes. There are estimated to be $1{\cdot}9 \times 10^{24}$ free electrons in a cubic centimetre of copper. The number $n$ of electrons which pass any point per second when the current is one ampere (or 1/10th of an absolute electromagnetic unit of current) is $8{\cdot}7 \times 10^{18}$ electrons.

If these pass in a wire having a sectional area of 0·01 square centimetre, that is, at a current density of 100 amperes per square centimetre, which is a usual density, then the velocity of drift of the electrons is $4{\cdot}55 \times 10^{-3}$.

The kinetic energy of motion of each electron if it has no other motion is $\frac{1}{2} m v^2$, and the number $(n)$ in motion per centimetre length of the wire is the number passing per second ÷ velocity $= \dfrac{8{\cdot}7 \times 10^{18}}{4{\cdot}55 \times 10^{-3}} = 1{\cdot}91 \times 10^{21}$.

So the energy per centimetre of length of the wire would be

$$\tfrac{1}{2} m v^2 \times n = \tfrac{1}{2} \times 0{\cdot}61 \times 10^{-27} \times 4{\cdot}55^2 \times 10^{-6} \times 1{\cdot}91 \times 10^{21} = 12{\cdot}1 \times 10^{-10} \text{ ergs.}$$

The coefficient of self-induction of 1 centimetre length of a straight round wire of area 0·01 sq. cm., that is, radius 0·0063 cm., may be calculated by the formula given by Russell ("Alternating Currents," vol. i, p. 60),

$$L = l\,(\tfrac{1}{4} \log_e d/a + 1),$$

where $d$ is the distance between the centres of the wires and $a$ the radius.

When the wires are alongside one another, $d=2\,a$, and this is the position of minimum self-induction,

$$L=3{\cdot}8\,l,$$

and the energy is $\frac{1}{2}\,L\,I^2=\frac{1}{2}\times3{\cdot}8\times10^{-2}=1{\cdot}9\times10^{-2}$ ergs.

The energy in the electrons is to the energy of self-induction as $12{\cdot}1\times10^{-10}$ to $1{\cdot}9\times10^{-2}$. Or as 1 is to $6\times10^{-8}$. That is, one six-hundred-millionth part.

## APPENDIX 3.

### On Kelvin's Statement as to the Cause of the Difference between the Energy Supplied and that Appearing as Mechanical Work.

It is difficult to understand what Kelvin had in mind when he gave the explanations in brackets (which do not occur in the original) for the difference between the energy supplied and that appearing or being absorbed as mechanical work.

He assumes a constant E.M.F., say, of a battery, and a current in each of two coils sustained by such E.M.F., and he states that if there is a gain of work, that is, if mechanical work is done, there will be twice as much work as this will be done by the E.M.F. "because the electro-dynamic induction produced by the motion will augment the currents." But by Lenz's law the electro-dynamic induction will be such as to resist the motion, so actually the electro-dynamic induction will reduce the current. Of the inverse case where mechanical work is done on the circuits against electro-dynamic forces he says, "there will be twice as much work saved off the action of the electromotive forces by currents being diminished during the motion." But in this case the currents will actually be increased.

What would actually happen in the case he cites is that in the first case the current would be diminished during the motion and part of the extra work would be supplied by a diminution of the electro-kinetic energy due to the smaller current, and when the motion had ceased the E.M.F. would continue to act and would again bring the current to the original value and augment the electro-kinetic energy. The physical explanation given by Kelvin in fact is not a correct one, though the fact he desires to explain is mathematically correct.

## APPENDIX 4.

(*a*) The value, given in the text for the value of the energy stored magnetically, assumes that the final value of $\mu=1{\cdot}85$ is constant during the process of magnetization, which is not the case.

It has been shown by writers on magnetism, that in the case of a material like iron, where $\mu$ varies with H, that if a curve is drawn connecting the values of H and B (the saturation curve as commonly called), then the energy contained in the iron is equal to $1/(4\,\pi)$ times the area of the space contained between the first ordinate, a line drawn parallel to the base line, and the B–H curve itself.

If $\mu$ be constant the B–H curve is a straight line, and this area becomes $\frac{1}{2}\,\mu\,H^2$ and the energy $\mu\,H^2/(8\,\pi)$ as before given. If the B–H curve is not straight the value is $\frac{1}{4\,\pi}\int_0^H H\,d\,B$.

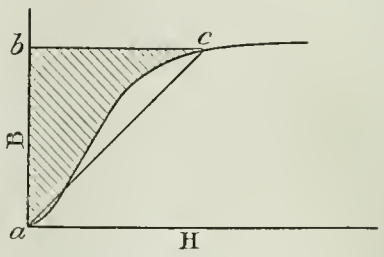



Fig. 23.

Fig. 23 shows the relation between the two, and the unshaded area between the curve and the straight line connecting *a c* represents the error arising by treating $\mu$ as constant.

(*b*) The work done in compressing air adiabatically may be thus calculated. The work done is shown in works on heat to be

$$W=\frac{p_0\,V_0/\tau_0}{\gamma-1}\,(\tau-\tau_0)$$

where $p_0V_0/\tau_0=53{\cdot}29$ ft.-lb. per lb. for air,
$\gamma=1{\cdot}41$, the ratio of the two specific heats for air.

So $W=\frac{53{\cdot}29}{0{\cdot}401}\,(\tau_0-\tau)$.

And $\tau=\tau_0\,(p/p_0)^{(\gamma-1)/\gamma}=\tau_0\,(p/p_0)^{0{\cdot}29}$

If $p_0=15$ lb. per sq. in.,
$p=300$ lb. per sq. in.,
and $\tau=60°$ F. $=520°$ absolute,

then $\tau=\tau_0\,(20)^{0{\cdot}29}$, from which $\tau/\tau_0=1{\cdot}86$ and $\tau=1{,}240$.

The volumes are then

$$(V_0/V)^{\gamma-1}=\tau/\tau_0 \quad \text{or} \quad (V_0/V)^{0{\cdot}29}=1{\cdot}86.$$

From which $V=V_0/8{\cdot}24$.

We can now complete $W=\frac{53{\cdot}29}{0{\cdot}4056}\{1{,}240-520\}$.

$W=96{,}000$ ft.-lb. per lb. of air
$=13$ cub. ft. $\times\,1{,}728$ cub. inches at 60° F.

This will compress to $\frac{13\times1{,}728}{8{\cdot}24}$ cub. inches $=2{,}720$.

So for the energy in 1 cubic inch of compressed air at 300 lb. pressure we have

$$W=\frac{96{,}000}{2{,}720}=35{\cdot}3 \text{ ft.-lb.}$$

## APPENDIX 5.

Kelvin showed that when two conductors forming part of one circuit and carrying a current moved towards one another under their mutual attraction doing mechanical work, the current being maintained constant, the electric energy supplied is double the mechanical work done.

This may be proved as follows :

The energy of the system is

$$W_{S1}=\tfrac{1}{2} L_1 I^2.$$

When $L_1$ becomes $L_2$, $W_{S2}=\tfrac{1}{2} L_2 I^2$ and the difference in stored energy

$$\Delta W_S=\tfrac{1}{2} I^2 (L_2-L_1).$$

The E.M.F. developed is

$$e=\frac{d}{d t} L I, \text{ or since the current is constant } I \frac{d L}{d t}.$$

The electrical energy supplied at each instant is $e I$, and the total energy supplied

$$W=\int e I d t=\int_{L_1}^{L_2} I^2 \frac{d L}{d t} d t=I^2 (L_2-L_1).$$

Hence the energy stored is one-half of the electrical work supplied, and the mechanical work done is also one-half.

This result would not be affected if the current in the two parts of the circuit had been supplied from different sources, and it is true in all cases.

## APPENDIX 6.

The efficiency of the stroke or cycle where the energy is constant throughout is thus calculated.

The energy is constant, so $\tfrac{1}{2} L I^2$ is constant and is equal to that put into the system at the commencement of the cycle $=\tfrac{1}{2} L_o I_o^2$ so $I^2=L_o I_o^2/L$.

The work done mechanically at each instant is

$$d W=\tfrac{1}{2} I^2 d L$$

So the mechanical work done is

$$W=\tfrac{1}{2}\int I^2 d L=\tfrac{1}{2}\int_{L_o}^{L_1} (L_o I_o^2/L) d L$$
$$=\tfrac{1}{2} L_o I_o^2 (\log_e L_1-\log_e L_o)=\tfrac{1}{2} L_o I_o^2 [\log_e (L_1/L_o)].$$

This is equivalent to the electrical work put in during the motion, to which must be added that originally put in. So the efficiency becomes

$$E=\frac{\tfrac{1}{2} L_o I_o^2 \log_e (L_1/L_o)}{\tfrac{1}{2} L_o I_o^2 \log_e (L_1/L_o)+\tfrac{1}{2} L_o I_o^2}=\frac{\log_e (L_1/L_o)}{\log_e (L_1/L_o)+1}.$$

## APPENDIX 7.

To Find the Maximum Value of the Coefficient of Mutual Induction between Two Coils Having Coefficients of Self-induction $L_a$, $L_b$, and also for the Case of a Given Number of Turns Divided between Two Coils.

If we have two coils ($a$) and ($b$) the E.M.F. set up by changes of the current in coil ($a$) is $e_a=L_a \frac{d I_a}{d t}+M \frac{d I_b}{d t}$, and this may be written as $e_a=n_a \frac{d Z_a}{d t}+n_a p \frac{d Z_b}{d t}$, where Z is the induction passing through the coil ($a$) due to its own current $I_a$, and $p_a Z_b$ is the proportion of the induction passing through ($b$) which also passes through ($a$).

$Z_a=n_a \mu_a I_a$ where $\mu_a$ is a constant,
$Z_b=n_b \mu_b I_b$ where $\mu_b$ is a constant,

and $M=p n_a n_b \mu_m$.

So we find $e_a=n_a^2 \mu_a \frac{d I_a}{d t}+n_a n_b p_a \mu_b \frac{d I_b}{d t}$.

That is $L_a=n_a^2 \mu_a$, $M=p_a n_a n_b \mu_b$.

Similarly it could be shown that

$$L_b=n_b^2 \mu_b \quad \text{and} \quad M=p_b n_a n_b \mu_a.$$

So it follows, that $p_a \mu_b=p_b \mu_a$. For a maximum value of M the coils must be geometrically coincident, and then $p_a \mu_b$ and $p_b \mu_a$ will not only be equal, but $p_a p_b$ will be 1 and $\mu_a=\mu_b=\mu$.

Then $M=n_a n_b \mu$, and $M^2=n_a^2 n_b^2 \mu^2=L_a \times L_b$.
So the maximum value of M is $\sqrt{(L_a \times L_b)}$.

If the number of turns to be divided between the coils is fixed, that is $n_a+n_b$ is fixed, the value of M will be greatest when the product $n_a n_b$ is greatest, which is when $n_a=n_b$.

## APPENDIX 8.

Graphical Construction for the Currents in a Pair of Short-circuited Coils.

The equations to the currents are

$$L_a I_a+M I_b=K,$$
$$L_b I_b+M I_a=K_1.$$

Rewrite these
$$I_a=\frac{K}{L_a}+\frac{M I_b}{L_a},$$
$$I_b=\frac{K_1}{L_b}-\frac{M I_a}{L_b}.$$

Draw a pair of axes O X, O Y (see Fig. 24).
On O X from O set off $x$ so that $O x=K L_a$.
On O Y from O set off $y$ so that $O y=K L_b$.

From the point $x$ set off a series of angles $\theta$ such that the tangents are a series of values of $M/L_b$.

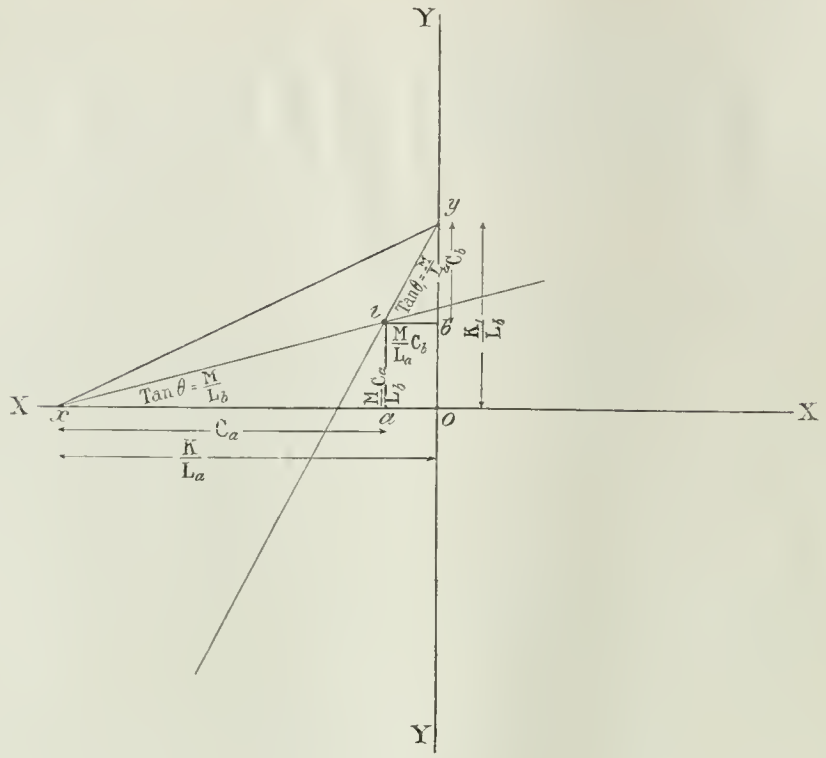

Y
y
i
b
$\frac{M}{L_a}C_b$
$\frac{K}{L_b}$
$\frac{M}{L_b}C_a$
$\frac{K}{L_b}C_b$
$\text{Tan}\,\theta = \frac{M}{L_b}$
$\text{Tan}\,\theta = \frac{K}{L_a}$
X
x
a
O
X
$C_a$
$\frac{K}{L_a}$
Y

FIG. 24.

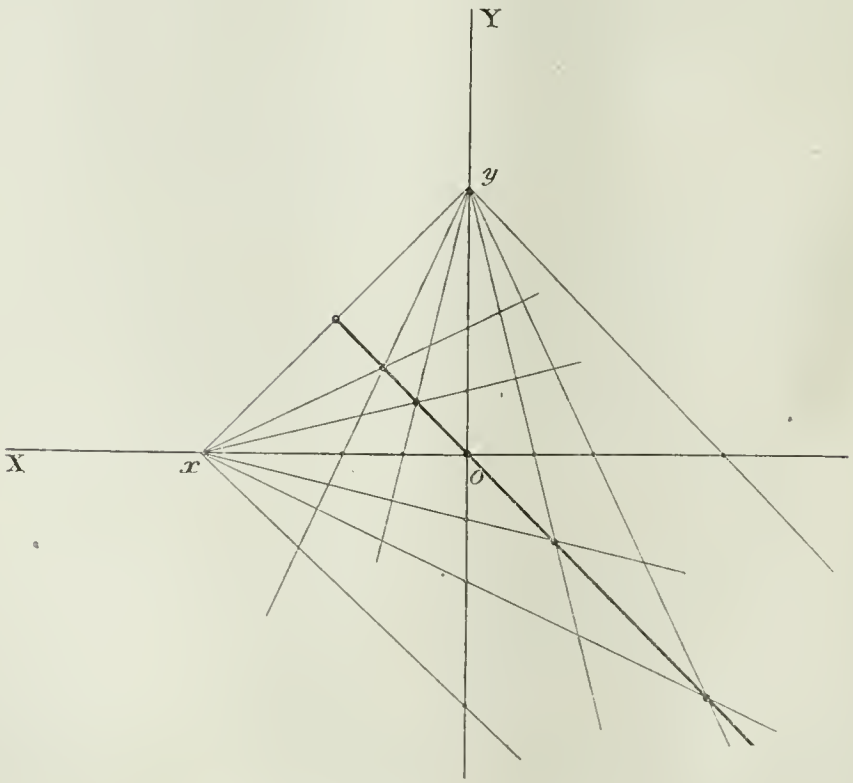

Y
y
X
x
O

FIG. 25.

From the point $y$ set off a similar series of angles $\theta_1$ such that the tangents are the same series of values $M/L_a$.

A series of intersections for each value of M occur, such as $i$.

Through these a curve may be drawn as in Figs. 25 and 26.

So that $x\,a$ and $y\,b$ represent for each point on the curve the value of the currents in the short-circuited coil.

In the case where the line $x\,y$ cuts Y Y the current in (B) is zero. No further movement will be produced by the electro-dynamic forces, but if M be still further increased, the movement will require mechanical force

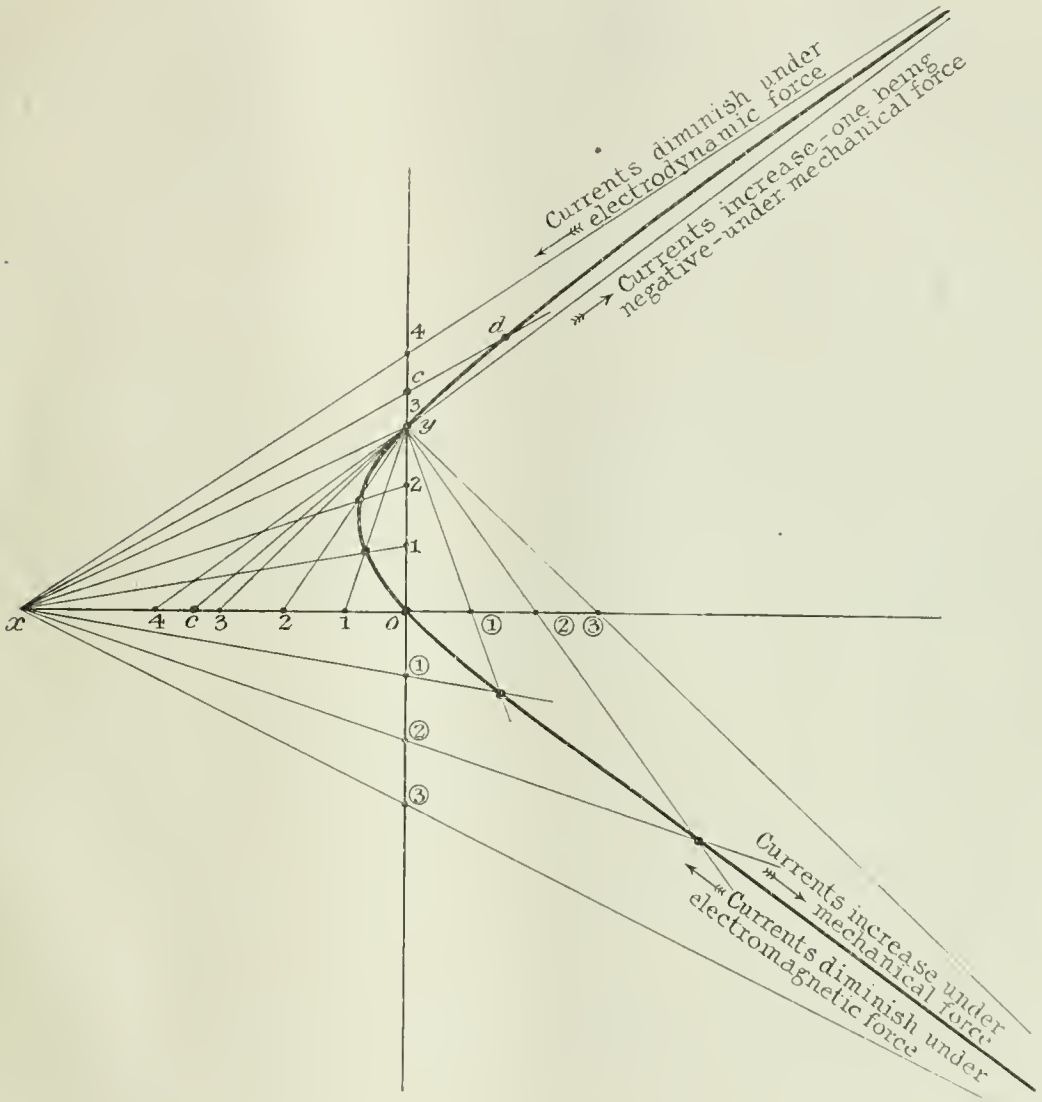



FIG. 26.

Consider the point $i$. Project it on O X, O Y by $i\,a$, $i\,b$.

Then $x\,a = x\,O - a\,O = x\,O - i\,b = x\,O - b\,y \tan\theta_1$,

$y\,b = y\,O - b\,O = y\,O - i\,a = y\,O - a\,x \tan\theta$,

and $x\,O = K/L_a$ and $y\,O = K_1/L_b$.

If we substitute $I_a$ for $x\,a$ and $I_b$ for $y\,b$, also $M_1 L_b$ for $\tan\theta$ and $M_1/L_a$ for $\tan\theta_1$, we have

$$I_a = K_1/L_a - I_b\,M_1/L_a \quad \text{and} \quad I_b = K_1/L_b - I_a\,M_1/L_b.$$

to produce it, and in this case $\theta_1$ must be set off in the opposite direction and the curve may be prolonged, $I_b$ now being negative, and thus continued till the maximum of M is reached.

A word as to the algebraic signs. In the figure as drawn, angles above O X and to the left of O Y are positive values of M, below O X and to the right of O Y are negative. Values of $x\,a$ to the right of $x$ are positive, to the left negative; values of $y\,b$ above $y$ are negative, below $y$ are positive.

It has been shown (Appendix 7) that the maximum possible value of $M=\sqrt{(L_a L_b)}$.

This arises when $\tan\theta=1/\tan\theta_1$ for then $\tan\theta\tan\theta_1=1$ or $\frac{M}{L_b}\times\frac{M}{L_a}=1$, so $M^2=L_a L_b$.

But $\tan\theta=1/\tan\theta_1=\cot\theta_1$, when $ix$, $iy$ meet upon $xy$ as in Fig. 25, or they are parallel with infinite currents.

In general M will not reach this maximum value.

If $q$ is the fraction of this possible maximum value of $\sqrt{(L_a L_b)}$ which gives the actual maximum and $p$ is the ratio of $L_b$ to $L_a$; then $M_{max.}=q\sqrt{(p L_a^2)}$ and $M/L_a=\tan\theta_1=q\sqrt{p}$.

Fig. 25 shows the diagram for the case where $L_a=L_b$ and $K=K_1$, and where the currents in the two coils are always equal, neither becoming zero.

The case of two coils revolving on an axis in the plane which contains both coils at two points in a revolution (Fig. 17) being a common case presents some points of interest.

Fig. 26 shows a complete diagram for such a pair of coils.

If the currents $I_a$ $I_b$ are established and the coils in the position M=0, the coils will move by electro-dynamic forces till the value of $I_b$ becomes zero. In the case shown $M/L_a$ is then unity. The motion is then continued under mechanical forces till M reaches its maximum value, which in the case Fig. 26 is 1·07 $I_a$. $I_a$ is then positive, $I_b$ negative. Continuing the movement the currents come over the same values till M=0 is reached, after which both currents increase to values greatly exceeding the original values, mechanical work being done on the circuits. When M has reached its maximum negative value the coils move under electro-dynamic forces, and at M=0 the revolution has been completed (see Fig. 14).

## APPENDIX 9.

The energy of the two coils is

$$W_1=\tfrac{1}{2}L_a I_a^2+M I_a I_b+\tfrac{1}{2}L_b I_b^2,$$

and

$$L_a I_a+M I_b=K.$$

After the B circuit is broken $I_b=0$

$$L_a I_{a2}=K \quad \text{and} \quad I_{a2}=\frac{(L_a I_a+M I_b)}{L_a}.$$

The energy $W_2$ now is $W_2=\tfrac{1}{2}L_a I_{a2}^2$, by substitution

$$W_2=\tfrac{1}{2}L_a I_a^2+M I_a I_b+\frac{M^2}{L_a}I_b^2.$$

The difference is $W_b$, the energy lost

$$W_b=\tfrac{1}{2}L_b I_b^2-\frac{M^2}{L_a}I_b^2=\tfrac{1}{2}I_b^2\left(\frac{L_a L_b-M^2}{L_a}\right).$$

In the limiting case where the coils are geometrically coincident and $L_a L_b=M^2$ the loss is zero.

# IRISH CENTRE: CHAIRMAN'S ADDRESS

By J. P. Tierney, Member.

(*Address delivered* 11 *October*, 1918.)

In considering what would form the most suitable subject for an opening address for the Session 1918–19, I have come to the conclusion that, in view of the extraordinary conditions through which the world is now passing, some general statement would be of more use than a paper on any technical subject. This address should therefore be taken as merely a few general comments on the altered conditions of the country to-day, and a suggestion as to the way in which electrical engineers can play an important part to the State.

At present several millions of men and women are engaged in this great world war, some actively engaged in actual fighting, others attending to the wants of the fighters at the Front, and others in equally important situations at home, preparing material for the Front and attending to the needs of those engaged there. All these people are, as it were, agents of destruction; and while admitting the enormous importance they are playing in the unfortunate conflict, they cannot be regarded as being employed in productive occupations. They are, in fact, of a negative value, as they are consumers of material rather than producers; even the results of the labour of the munition workers and others who are producing material are for no other purpose than to assist in destroying human life. As more men and women from each nation are taken into the conflict and enter the ranks of the different services, and as more nations enter into the conflict, the number of unproductive persons in the world enormously increases. Therefore the strain and demand which is being put upon the energies of the remaining members of the population is daily increasing. First, because the number of people whose needs have to be met on account of their relation to the war has increased, whilst at the same time the number of producers is automatically reduced. It therefore follows that it is for the country to devise the most efficient and economical means of production of everything necessary for life and the war. The efficiency of the producers can only be improved by more up-to-date methods and improved appliances in all directions. These improvements can only be effected by placing in the hands of the producers a plentiful supply of power. Therefore, there never was a time when the world had greater need of engineers and of trained technical men. Not only is engineering the foundation of modern society, but it permeates the whole structure. Anyone who doubts this has only to consider what would happen in any country if the work of the engineer should suddenly cease.

Our system of transportation, railroads, trolley lines, steam-boats, subways, automobiles, transmission by telegraph and telephone, wagon roads, bridges, tunnels, streets, buildings, workshops, mines, and every luxury and every necessity are all dependent upon the work of the scientist or the engineer, not only for the recreation of the people, but for their continuous and successful existence. When we stop to consider the enormous loss of life which has already occurred and the additional loss which unfortunately is sure to follow, when we try to realize the almost inconceivable amount of property damaged and the destruction which has been wrought throughout Europe and on the high seas, and when we think of the enormous amount of food-stuffs, munitions, machinery, and supplies of all kinds that are absolutely necessary in carrying on a struggle of such magnitude, it can be readily understood that engineers are destined to take such a conspicuous part in the affairs of the world in the near future.

The value of any commodity is the basis of the law of supply and demand, and with the supply limited and the demand practically unlimited the value of commodities is bound to be high This law applies equally to manual labour and all other forms of human effort. This being true, think of the enormous amount of reconstruction which will have to be done. Reconstruction of work representing many years of hard labour and fabulous sums of money. Railroads, bridges, highways, industrial plant of all kinds, and even entire cities, in the boundaries of which are included every kind of construction imaginable. Then, on the other hand, consider the valuable supply of raw material, the limited manufacturing facilities, the shortage of man-power—skilled mechanics and artisans of all kinds as well as common labour—and we shall readily conclude that it will be difficult to over-rate the importance of the engineering profession when peace finally comes.

I need not dwell on the question that the only method of transmitting energy is electrically. To provide any district with a cheap and ample supply of electric power is the first and most essential factor of output. This supply of power means at once a demand on our coal resources, unless natural sources of power are employed. Coal may now be described as the burning question, and we are asked on all sides to economize coal. We should therefore turn at once to the natural sources of power and develop these to their utmost

A plan which would be productive of the greatest relief in the shortest time includes the general development of all available water-powers, hydro-electric stations being erected at points where water-power is available; and these stations should be connected electrically by overhead transmission lines.

In sections of the country not favourable to water-

powers or peat supply, coal will continue to be the source of power, but in this case the coal should be consumed in power stations situated at the mouth of the mine, arrangements being made to extract from the coal all the by-products at present wasted and the energy being transmitted over high-tension lines to centres of distribution, instead of hauling the equivalent amount of coal to the steam plant located in the cities and towns remote from the mine. This plan of general water-power development and the generation of current at the mine would give a great impetus to the general electrification of the railways, it being now an admitted fact that the steam locomotive consumes about 6 lb. of coal per horse-power hour, as compared with the modern steam turbine which consumes about one-third of this amount. Such a scheme of power generation and transmission will automatically place at the disposal of the agriculturalist living in the country adjoining the transmission line a supply of cheap electric power for agricultural work of all kinds. It possesses the advantage of utilizing our natural sources of power at present running to waste, also the recovery from coal of the available by-products now being wasted, in addition to consuming coal in the most efficient method now known.

In Ireland we have the peat question, which has been the subject of investigation by a Committee, who have heard a considerable amount of evidence on the matter and whose Report I understand will shortly be published. It is well known what can be done with peat once it is recovered and the water partly or wholly extracted from it. There are several very valuable by-products, and the heat generated in recovering these by-products can be utilized for the production of power and the generation of electric current. The one important factor which it is necessary to experiment with is to ascertain what is the best method of reducing the water content. This will take some little time to settle.

A further source of power in this country is the rivers. Whilst admitting that, with the exception perhaps of the Shannon and the Erne, we have no places where large hydro-electric plants can be established, we have on the other hand a large number of places where small powers can be developed. It is sometimes held that for a hydro-electric station it is necessary to construct extensive works to bring the water to the point where the power station will be placed. This matter has been engaging the attention of our American friends for the past 12 months where the coal question has been almost as serious as here, and the conclusion arrived at by those investigating the question is that on every river having a reasonable volume of water this water should be harnessed at each point of the river where there is a reasonable fall, and all the power stations so constructed be connected to one transmission line. The principle is followed that just as power is at present distributed electrically, so should it be collected. When we consider this question this is the sensible solution, as it frequently happens that we shall obtain on a short stretch of a river a fall of 20 or 30 feet, the next two or three miles being comparatively level, and then a further series of rapids or falls. Now, assuming that the water is taken from the beginning of the first set of rapids and discharged through a power station, at the end of the second set some two or three miles of canal or pipe line is necessary and the only advantage gained is perhaps a foot or two of fall, which does not compensate for the increased capital outlay. On the new principle the power is conveyed from one power station to the other on the ordinary transmission line.

Until the advent of the induction generator this scheme was not quite practicable, as each power station would have to contain, in addition to the turbines and alternators, exciters, governors, and other auxiliary apparatus. With the induction generator these auxiliary apparatus are only installed at one power station which controls the other stations running in synchronism with it. Likewise, the question of staff in the case of the station fitted with induction generators is reduced to one of periodical inspection, the station being practically automatic. The practice is to install at the latter station a turbine and low-voltage induction generator, the latter being permanently connected to step-up transformers, which in turn are connected to the transmission line with time fuses and disconnecting switches.

It is sometimes held that a particular hydro-electric scheme is no use because at certain periods of the year the supply of water falls very low. In this country we have an abundance of rain, generally too much from October to May. This period in the case of Dublin is the period of greatest load. It is therefore economical to install, on any river, plant capable of dealing with the average flow of that river during the months of October to May. This plant would work in synchronism with an auxiliary steam plant which makes up the shortcomings of the hydro-electric station.

I had the opportunity in 1908, and again in 1910, of inspecting in detail and getting all particulars of the power supply to the City of Munich and the surrounding country, and I will here briefly refer to the system.

### Isar Works, Munich.

These hydro-electric works are situated on the River Isar about 20 miles from Munich. The works necessitated the construction of over six miles of canal, which has been cut parallel with the river. The actual fall between the point where the water first leaves the river and enters the canal to the point where it is finally discharged into the Isar is about 33 feet.

Power station No. 1 is situated at a point approximately $\frac{3}{4}$ kilometre from the starting-point of the canal, and power station No. 2 is situated at a point nearly 3 km. farther along, the length of the tail water of No. 2 power station being nearly $2\frac{1}{2}$ km. In the case of power station No. 1 the tail race naturally constitutes the head race of power station No. 2. The level of the water in the canal at the point of discharge from No. 1 power house is about 7 feet lower than the level of the river at this point. The canal, being constructed on just sufficient grade to enable the water to flow, comes level with the river at a point about 1 km. farther

along; after this point it gradually rises above the river. The same principle is applied at power station No. 2, the tail race being carried to a point where it becomes level with the river.

On the occasion of my visit to this installation in 1910 the plant at power station No. 1 consisted of four turbines, each of 500 kw. capacity. In addition there was a stand-by steam plant consisting of reciprocating engines amounting to 2,000 h.p. Power station No. 2 contained four water turbines, each with a capacity of 700 kw. The current generated at these stations was three-phase, at a pressure of 5,350 volts. Each power station fed into an overhead transmission line, which was carried to the outskirts of the City of Munich, where underground cables carried the current into a main distributing station at the centre of the city. A second auxiliary steam plant was installed at the distributing station which made good the difference between the power which the Isar stations were at any time able to supply and the demand. This network supplied all the power for lighting and industrial purposes in the city of Munich, the Munich Tramways, the Isartallbahn, which is the railway connecting Munich with the Isartall district, and the power for industrial and agricultural requirements in the surrounding country.

The scheme appeared to be designed on the lines of getting at all times everything possible from the river, and making up the deficiency of the latter with the steam plant. The total amount of power at the two water-power stations was 5,000 h.p. The steam reserve at one of the water-power stations, and at the station in the city of Munich, was the same figure, making a total of 10,000 h.p.

On the occasion of my visit I was informed that there were connected to the mains 766 motors, totalling nearly 5,000 h.p., for industrial purposes, and 254 motors in the country for agricultural purposes. Portable motors were extensively used on the farms, these being let out on hire to the different farmers at so much per day.

In 1906 I visited the North of Italy to see the first example of three-phase electric traction on the Italian State Railways, the Valtellina line having just then been opened. In this case the power was obtained from the River Adda, and I have prepared the following notes on the power station, which is of interest as another example of hydro-electric development.

### Valtellina Scheme.

This line was the first case of three-phase electric traction on the Italian State Railways, the power being derived entirely from water power, the power station being situated at Morbegno on the River Adda 110 km. from Milan. The water is derived at a point on the river 5 km. above the power station. The water is carried in an open canal for a distance of 1,900 metres and thence through a tunnel 2,900 metres long. At the termination of the tunnel a short pipe line consisting of two pipes, each 2 metres in diameter and 68 metres long, are carried from the end of the tunnel at an angle of 45 degrees down the hillside to the power station.

On the occasion of my visit three turbines each of 2,000 h.p. had been installed, and a fourth of 3,000 h.p. was on order. The water from the turbines discharged into a tail race 100 metres long and 20 metres wide, which discharged into the River Adda.

The work was carried out by the Ganz Company of Budapest, the turbines being of the Frances reaction type, running at 150 r.p.m. and generating, on a head of 30 metres, 1,050 kw. with a power factor of 0·7, the alternators being three-phase, 15 periods, and generating current at 20,000 volts.

Arrangements were provided for guarding against excessive rise in voltage by an automatic arrangement, which cut down the excitation of the alternators in case of any sudden rise of voltage either due to a surge, or due to the speed of the turbines increasing.

This installation is a fair example of the amount of hydraulic work sometimes necessary to obtain a comparatively small fall, as it necessitated the construction of 5 km. of canal, tunnel, and pipe line, in order to obtain a head of 30 metres.

The actual difference in level in the River Adda between Desco and Ganz was only 35 metres, or approximately 110 feet. Nevertheless, the scheme was considered well worth the cost.

It is interesting to note that the farthest point of the railway from the power house in 1906 was 59 kilometres, and the distance from Milan, to which city it was proposed to supply current, the transmission line being actually in course of construction, was 110 km. Since then the electrification of the Italian Railways on the three-phase system has proceeded steadily, due to the fact that large water powers are available in the North of Italy, whereas coal had to be imported principally from Germany at very high cost. It is interesting here to note that at present when Italy is suffering badly through the coal shortage, as naturally import of coal from Germany is stopped, a large amount of electric power is being imported into Italy from Switzerland by overhead transmission lines across the frontier.

### Vancouver:

Another example of hydro-electric development working in conjunction with the steam power station, particulars of which I have also obtained, is that of the British Columbia Electric Railway Company which supplies all the electric power to the city of Vancouver. In this case the hydro-electric station has been erected at Lake Buntzen some 20 miles from Vancouver with a capacity of 33,000 kw. An auxiliary steam plant is in operation in Vancouver with a capacity of 6,000 kw. These stations work in conjunction with one another, the steam plant simply taking up any load which the hydro-electric station is unable to do.

### Power from River Liffey.

It might at this stage be asked what interest are these schemes to Dublin. The reply is that we have now in Dublin an opportunity of harnessing the power of the River Liffey and of arranging for hydro-electric stations to be erected to work in conjunction with some of the existing steam stations already installed in the city of Dublin, the scheme being carried out on exactly similar lines to those at Munich or at Vancouver which I have just described.

I have investigated the possibility of water power from the River Liffey at the Falls of Poulaphouca and at the Golden Waterfall near Ballymore-Eustace. I have made measurements of the flow of water and obtained levels, the following being briefly a description of the scheme:—

"Both these falls are situated on the River Liffey at a point 23 miles from the centre of Dublin, and approximately 19 miles from the nearest point of supply of the Dublin Corporation Electricity Department and the Dublin Tramways.

At Poulaphouca the river, which up to that point flows through a fairly flat country, suddenly enters a gorge, the sides of which are about 80 feet high. The river flows through this gorge for a distance of about 250 yards, in the course of which it falls 25 feet by a series of rapids. It then turns at right angles and flows over the falls proper, which have in the three steps a total head of 62 feet. From the foot of the falls to a point 150 yards below the same there are a number of rapids which give a further head of 17 feet.

By constructing a dam across the river immediately above the falls the water can be raised 25 feet, which will leave the water at this point level with the point where the river enters the gorge. This additional head will therefore be obtained without flooding any of the flat country above mentioned.

The cheapest method of obtaining the total head of 104 feet which the three figures mentioned above amount to, is to construct the above dam and lead the water from the same through a tunnel in rock for a distance of 50 yards, and then carry a pipe line for a further 150 yards, or construct a tunnel all the way.

I made some sections of the river and took velocity tests which show the flow to be 9,000 cubic feet per minute. Allowing the usual efficiencies for turbines and generators would show that on this particular evening the falls were good for about 900 kw. The average summer flow may be taken at $1\frac{1}{2}$ times this figure, and the average winter flow from October to April at about three times, or a total of about 2,700 kw.

At the Golden Water the river flows over a cliff giving a sheer fall of 22 feet. It is possible at this point to construct a dam across the river about 20 feet high, which will have the effect of lifting the water at this point to the level of the water of the Poulaphouca power house, and will only result in flooding about 10 acres of poor land in the section between the two power houses, which would be situated half a mile apart.

The volume of water at the Golden Waterfall is the same as at Poulaphouca, and the head being approximately two-fifths of the head of Poulaphouca the power will be in proportion.

It therefore follows that if a power station is erected at Poulaphouca Waterfall and another at the Golden Waterfall, it can be calculated that in summer a minimum of about 1,250 kw. and an average of about 1,900 kw. can be obtained, and in winter an average of about 3,500 kw.

The scheme would therefore be to erect these two power houses and connect them by an overhead transmission line starting from the Golden Waterfall and connecting with Poulaphouca Waterfall and thence to the City of Dublin.

If the water power available at Poulaphouca and at the Golden Waterfall at Ballymore-Eustace were harnessed by the erection of hydro-electric stations at each of these two points, one transmission line would convey the power from Poulaphouca and the Golden Waterfall into a distributing centre in the city. These two hydro-electric stations would then operate with the existing steam stations, the load being regulated from a distributing station by an official who is termed in America a load controller, his duty being to arrange that at all times the full capacity of the hydro-electric stations would be utilized, the steam station merely making up for whatever difference would exist between the power available from the hydro-electric stations and the demand.

Two of the schemes which I have described above, namely Munich and Vancouver, are operated on these lines, and from information which I have gathered I am of opinion that the coal consumption at the steam station would be reduced to a fraction of what it is at present.

The distance between Poulaphouca and Dublin, namely 23 miles, may appear to a layman an unworkable distance. To clear the air on this point I may mention that the new power station—hydro-electric—which has been erected at Keokuk on the Mississippi River supplies the power to the city of St. Louis 150 miles away.

Members present are all acquainted with the recommendations of the B.O.T. Committee as to the abolition of the numerous small power stations in England and the concentration of power in bulk to one station. Owing to difference in systems, voltages and periodicity, to say nothing of local and personal interests, this scheme of a super-power station is confronted with innumerable difficulties.

In Ireland, owing to the absence of any power schemes, such difficulties do not arise and the electrical engineer has a clear field to lay out his schemes on the most modern and economical lines, and, in doing so, the natural resources of the country should get his consideration.

There is a general feeling that more facilities for the development of Irish industries and mineral resources will be given in the future than in the unfortunate history of the past. It therefore behoves all Irishmen to use all their energies for the development of their country's resources, and to assist in every way in the development of these resources. The unfortunate history of the past should be forgotten, and the feeling of pessimism which often pervades when the suggestion is put forth to start a new industry, should give way to a feeling of optimism. It does not necessarily follow that a scheme which was a failure in the past will be a failure in the future, as we all admit that science has enormously developed within the last 20 or 30 years, and the resources at our disposal to-day are infinitely better than they were 20 years ago. We must make use of this progress, not permit old institutions to stand in the way of development, and always remember that what has been worked successfully in other countries can equally well be worked in our own.

# WESTERN CENTRE: CHAIRMAN'S ADDRESS

By H. I. Rogers, Member.

*(Address delivered 14 October, 1918.)*

I want to deal this evening more particularly with what appear to me to be the lessons of the War for electrical engineers. I am going to approach the subject from the manufacturer's point of view, which in my opinion is the basic one and that from which the whole industry should be controlled. All industry should, and I believe will, be treated in the future entirely from the national point of view. It has been rightly described as the touchstone of national life, and it cannot be said by any stretch of imagination that it was so treated before the war. We should treat it in future not only as a national question but as an imperial one, because if the war has taught Great Britain any lesson it is surely the value of the Empire to the whole nation. I hope that in the future guidance of industry this fact will be fully borne in mind, and that the vast potential resources and purchasing power of the whole Empire will be fully realized.

The guidance or, I should say, want of guidance of the electrical industry was, I think, the principal factor in its want of success. Instead of each individual working as if he was guarding a great national trust, we were all engaged in unnecessary and destructive competition amongst ourselves; and instead of trying to help each other and thus build up the productivity of the country, we were all engaged in an attempt to ruin our competitors. In fact we were working simply for our own private ends.

A great proportion of the best minds and best organizing ability has been frittered away in a vain attempt to bolster up most inefficient methods of power distribution. Science, which after all forms the basis of the electrical industry, was practically divorced from it owing to the non-success of the industry, due to the further causes to which I want to draw attention.

Too many consulting engineers vied with power distribution engineers to force manufacturers to depart from well-established practice. Manufacturers, instead of being prepared freely to exchange the results of their experience and knowledge amongst themselves, were engaged in a fratricidal war. They have now learned the advantages of protection and, while not perhaps of Government control, they can now appreciate Government co-operation. They have also fully realized the enormous importance to industry of standardizing their products to the greatest possible extent, thus bringing in the time element which is the foundation of success, as the cost of work is proportionate to the time it is in the works.

The workers in the industry, as in all others, were in a state bordering on revolution, and it will be one of the most difficult problems in dealing with the question of reconstruction to teach the worker that if he wants higher wages, shorter hours, and consequently improved conditions of life, he must produce to the utmost of his capacity.

We are all then agreed that the position of affairs before the war was extremely unsatisfactory, the industry was in a very poor state financially, and if proof is wanted of this I would say that in evidence given to the Committee on the Position of the Electrical Trades after the War it was shown that 32 electrical firms with an aggregate initial paid-up capital of just over £15,000,000 had had to write off no less a sum than £3,125,000; and the tables further showed that few of such companies had ever earned a satisfactory return on their capital.

Turning to the Coal Conservation Sub-Committee's Report, we find described a most chaotic state of affairs. As regards power distribution we have 600 undertakings supplying power, and of these those which have power stations have an average generating-plant capacity of 5,000 horse-power, or about one-fourth of the capacity of a single generating machine of what the Committee consider to be an economical size. We see that because no large central supply was available 8 power stations have been added in the last few years to the 21 already existing in London, and it is further stated that all these 8 stations are badly situated as regards water facilities. We are shown that a man who lives, say, at Hampstead can during his day's work travel by trains or be in buildings supplied by 5 or even 10 undertakings without doing anything exceptional. Figures are given that the charges for electric power in the great manufacturing district of Lancashire average in 23 areas 1·32d. per unit, whereas the price paid for electrical energy averages less than ½d. per unit in the less densely populated North-East Coast district where power is supplied by a group of power companies from one interconnected electrical distribution system. I would here say that those companies have one 15,000-h.p. motor installed and another of 20,000 h.p. is now being fixed. We have the result of all this and other inefficiencies summed up by being told that 55 million tons of coal are being wasted per annum, and a possible national advantage of £100,000,000 per annum is being lost because we have allowed our electric power supply to be carried out in an exceedingly inefficient manner; and even this figure of 100 million pounds does not take into consideration the manufacturing and industrial advantages of a cheap and efficient electric power supply.

I propose to consider now in detail the causes that led to this extremely unsatisfactory state of affairs. I would summarize these causes, not necessarily in the order of their importance, as follows:—

(1) The extremely unsatisfactory method of power distribution, to which I have already referred, led to high cost of power, thus crippling the industry.

(2) The policy of free imports.

(3) The disadvantage of municipal control.

(4) The status of the engineer

(5) The divorce of science from industry.

(6) The harm often done to the industry by the consulting engineer.

(7) The criminal folly of allowing merchants to compete with the home industry by selling too cheap foreign manufactures.

(8) The damage done by unnecessary internal competition and want of knowledge of the advantages of specialization on the part of manufacturers.

(9) The want of proper education of the worker.

As regards power distribution, and also in respect of the manufacturers, we have all been engaged in pioneer work. What is possible to-day was not possible, say, 10 years ago, and consequently development has had to be dearly bought, because discoveries and improvements have made obsolete much of the material upon which great expenditure was quite justifiably incurred only a few years back. At the same time it must be remembered that we in Great Britain have been heavily handicapped because of the cheap cost of coal and the highly developed state and efficiency at the inception of the industry of the steam and gas engine—disadvantages which our foreign competitors had not at any rate to the same degree.

Then our Government, with the approval of a majority of the people, allowed foreign manufacturers to dump their products into this country without their paying anything towards our taxes or rates, thereby permitting them to increase their products and so reduce their costs by increasing their markets and making ours smaller, and thus rendering it more difficult for the British manufacturer, who was already sufficiently handicapped, to make his business a properly paying concern. For the same reason manufacturers also found it impossible to raise the capital for new developments, with the result that the manufacturing in connection with such developments, as well as the new industry itself, to a great extent passed to foreign countries.

The policy of municipal control of electricity supply has proved most disastrous. At the commencement of the electrical industry not much could have been said against it except on political grounds, but from an engineering point of view it has now proved to have been a gigantic mistake and one which will have to be remedied immediately, because municipalities have had of necessity to operate in comparatively small areas. Opinions differ as to how this shall be done, but what is clear is that no such inefficiency as exists to-day should be allowed to continue for a moment longer than necessary. It is perfectly clear that the control of such a vital part of the industry cannot possibly be allowed to remain in the hands of local Electricity Committees which are almost entirely composed of people who are absolutely ignorant of the subject with which they have to deal. The whole business must be raised on to a much higher plane and engineers must control their own affairs with Government co-operation. This would release many of our best men for industry.

Before leaving the question of distribution I should like to point out that, if the industry is to flourish as it might do, the cost of power must be enormously reduced. I can only speak in pre-war figures, but it is perfectly obvious that if power could be supplied at an average of ½d. per unit on Tyneside, it need not have much exceeded that figure anywhere if the supply had been efficient. All of us can appreciate what this would mean as regards the manufacture and sale of electrical machinery. We are told that the amount of power per worker used in America is double that which is used here, and that where in Britain £33 value of home-made electrical machinery is consumed per 100 people, £70 is used in Germany.

This brings me to another most important cause of the non-success of the industry, and that is the question as to why the country did not appreciate the paramount importance to the nation of the electrical engineer and engineers generally. We have always quite rightly had a very good opinion of ourselves, but broadly speaking we have not taken our proper place in other people's regard. Anyhow the war has proved the enormous importance and, indeed, indispensability of the engineer, and what we have to do is to see that the country does not forget it in future. How is this to be done? Are we sure that we were not ourselves to blame to a great extent? Has even our Institution in the past taken the proper steps to improve the status of the electrical engineer? Why has this question of obtaining a Charter, which would once and for all put the matter on the right basis, not been settled? If there has been any explanation in the past there is none now, so let us see that it is pushed through energetically. Here too I would enter the strongest protest against the policy of the Institution in attempting to separate the technical side of the business from the industrial one. The thing cannot be divided, and in the future the industrial side of electrical engineering will have to be looked upon as the all-important one.

Given then our Charter and the settlement of our little differences, is the engineer going to take his proper place in society? I am afraid not at once; we must inculcate into the budding engineer much more idea of the enormous importance of his work to the national life, he must take more interest in the national life, but above all we must see that he is very much better educated not only from a technical point of view but from that of a man of the world. I believe there is not nearly enough ambition among engineers, and that too many splendidly equipped men remain in the ranks of the consulting and distribution side of the industry, sometimes, alas, with an extraordinary idea in their minds that they are improving their social position.

Arising out of this I think a great effort ought to be made in Bristol, and other cities where such a thing does not exist, to start a club or institution where engineers and scientific people might gather together for exchange of views and meetings, and where a good reference library and all the technical papers both British and foreign might be available for the members. One great result of the war has been to bring us all much closer together, and I believe the present time offers a most suitable opportunity for the starting of an institution of the kind. I am perfectly certain that

such a meeting place would be of inestimable value in bringing us together, getting to know one another better, and preventing the old quite unnecessary professional and business rivalries. The question of finance would clearly present considerable difficulties, but I believe that considering the number of engineers in, say, Bristol this could be got over if a not too ambitious start were made. Clearly, here it would have to be open to all *bona-fide* engineers as there are not sufficient electrical engineers to make such an institution a success.

One of the greatest causes of the non-success of the industry has been really brought about by its non-success, and that is the separation between it and science. I think that in future there should be two paths open to the scientific man. First, teaching and scientific research in universities and Government institutions; but even here I believe the industry must to a great extent control the teaching and to some extent the research work. This perhaps will come about by manufacturers adopting what is called the sandwich system of education for their apprentices and boys, and so be brought more closely into touch with the teaching profession, which would undoubtedly keep them more up to date with scientific research work and would also, I hope, lead to the teaching profession being brought more into touch with industrial and practical difficulties of which they in the past have had no conception, thus leading to a very great deal of misdirected energy. The higher branches of scientific research no doubt will always be carried on in the universities, but there is secondly a very great opening indeed for scientific research with a still more practical bias in the workshops of the country, and I look forward to a great advance on the part of manufacturers in applying science to their work, and the consequent necessity of employing scientific men who would be able to afford the time for the necessary research work in connection with problems that are always arising in any big industrial undertaking. The smaller firms of course would undoubtedly have to rely for any research work they wish carried out on the universities or Government institutions, which would help again to keep them more in touch with the world. I hope too that the scandal of the low pay of the scientific worker will be done away with, and from the fact that a great many more of them will be employed in industrial work, they should be enabled to and must demand much higher remuneration, perhaps through the instrumentality of their professional organization. I will not call it trade union.

This brings me to the subject of the consulting engineer, and I think that with the development of the industry his present occupation will largely disappear. With a highly developed technical side of the industry the manufacturers, for their own reputation's sake if for nothing else, will be practically invariably able to advise properly and engineer their contracts, and I believe that the consulting engineers of the future will fulfil similar functions to those of the consulting physician or surgeon.

This will lead to a great increase of standardization, which is a question of the utmost importance to the industry. My firm has been engaged for the last $3\frac{1}{2}$ years in the manufacture of shells and we have found that while the wages per head have rather more than doubled, the output per head has quadrupled in value and this not because of war prices—as shell is one of the few commodities the price of which has been greatly reduced since the war began. Nothing like shells can be expected in peace times, but I would ask members whether the most successful manufacturing firms are not invariably found to be engaged in repetition work. The best example of this in the engineering world is the Ford Company; the price of the Ford car has been down to practically £90, and the firm now hopes to get it down after the war to £75. Meanwhile they pay £1 a day minimum wage, have £13,000,000 in the bank, and have 38,000 contented workers.

If these figures do not force members to see the paramount importance of standardization, nothing will. The man who unnecessarily departs from standard practice is committing a crime against the community, because greater standardization and less competition, which would follow, mean greater output, greater output necessitates more power and machinery, more power and machinery mean higher wages and salaries, not only to the workers but to all of us. If we want to pay even the interest on our debt after the war we must have greater production and no limitation of output. We must not want to buy cheaply but to produce cheaply. The objection will be raised by many that if standardization is taken too far progress will suffer, but I would reply that standardization means bigger profits, which, broadly speaking, means advance, and that it is the want of standardization which means stagnation in industry.

Then again we must see that a stop is put to the too great activities of the merchant. Of his value as an exporting and distributing agent everybody is convinced. There are firms known to all of us which have been of the greatest value to the British producer, but there are many, too many, which have directly injured the manufacturer by simply factoring foreign machinery and apparatus to the obvious detriment not only of the manufacturer but also of the worker and thus of the whole community. Unfortunately, in many cases these people have not only done this but by doing so have helped to arm the nations who are our enemies in the field at the present time.

I now approach perhaps the most important cause of the failure of the industry. I refer to the excessive and unnecessary competition between different manufacturers. Before approaching the subject, however, I should like to read a few extracts from letters I have received from various firms in answer to letters of mine asking for their views on the question as to what are the causes of the failure of the industry in the past and what is wanted to make it more successful in the future.

One great firm says that in its opinion restrictive legislation and the fact that the home industry was not supported by Government departments and municipal and other public bodies are the principal reasons

for its failure, and that what we want is that manufacturers' standard models should be accepted and that increased standardization is required.

Another thinks that hostile legislation and the economic basis of buying in the cheapest market are to blame and have paralysed the industry. They think that electrical apparatus is inherently cheap if it is manufactured under right conditions for cheap production for which it is particularly adapted. These conditions mean that production of all parts should be on a repetitive basis, and, if so, quality can be of the highest and conditions of the workers can be of the best; but this can only be done if the purchasing public will buy the resulting apparatus and not insist on introducing variations which make production impossible under the above methods. Our workpeople want better conditions and higher wages, and the only way to do this is to increase the productivity of the workers; and electrical machinery and apparatus is the most useful agent for this purpose. The consumer must, however, standardize his requirements. The manufacturers must produce apparatus which will stand the acid test of service; this means the best design, which under proper conditions of manufacture costs no more than apparatus of poor design. Under these conditions the industry would be profitable to the workers and ensure good wages; it would be profitable to the manufacturer and ensure financial stability; and it is profitable to the consumer because it would ensure him machinery of good quality at a reasonable cost. They fear that the workers and trade union leaders do not show any real appreciations of these fundamental principles, to which I agree.

Another firm believes in commercial and technical alliances between manufacturers, leading to an interchange of the best points in the several designs of each concern and thus doing away with the old keen competition.

It will be seen from the above that all the firms in question are in absolute agreement, though their views are expressed differently, that the old cut-throat competition which existed between different firms who spent an enormous amount of time and money in unnecessary competition between each other, hoping thereby to crush competition some time or another, must give way to a full realization of the value of intensive production and the consequent absurdity of trying to make too many things.

A matter of vital importance to the industry has been the want of properly educated workers in it. Much more interest should be taken by the engineer in educational matters. Since the commencement of the war the manufacturing engineers in Bristol approached the Education Committee and asked them to afford better facilities for giving technical education to our prospective employees. They were most anxious to meet us in every possible way, and in September 1917 a junior Technical School was started which I think is going to prove of the greatest success and will be of enormous value to the industry in future. The boys go to the school after leaving the Elementary School and have two years whole-time education with a considerable technical bias, and at the same time quite rightly general education is by no means neglected. The manufacturers have undertaken to absorb these boys in their works when their time expires. The effect on the boys is most remarkable. They quite realize the opportunity which has been given them and, as stated above, I look forward to the best possible results from this school. Of course there are many similar schools in the country, and on the other hand there are many localities in which nothing of the kind has been done. From our experience in this district with the Education Committee we should strongly recommend engineers in all districts where such a thing is possible to approach their Education Committees with a view to starting similar schools.

A further advantage has been taken of this Technical School in as much that several firms are sending a number of their apprentices for one whole day a week for technical education. Their general education also will not be neglected, which will have the result of doing away, as far as these boys are concerned, with the miserably inefficient and unsatisfactory evening classes.

With the spread of education amongst the workers, and the awakening thereby of a fuller realization of the enormous importance to the nation of each man giving his best not only for purposes of self interest but also for the good of the community, I feel sure that industrial unrest can be greatly reduced. At the same time the workers who are now in the industry must be taught to realize by practical means that production is the basis on which all wages are paid; and that, by standardization, consequently improved methods of production, and the willingness of the worker to do his best, greater production can be obtained and we shall be able to avoid the cloud of industrial unrest which so many of us fear is going to burst on the country after the war.

To sum up, what we want is not to buy cheaply but to produce cheaply; and the co-operation of all branches of the industry—the scientific men, manufacturers, consulting engineers, distribution engineers, merchants, and, last but not least, the workers, is wanted to bring about the desired result. How this co-operation is to be achieved is a difficult question. We cannot get a Marshal Foch to take supreme command of the industry and show us the advantages of unity of command, but what we can ask for is Government co-operation and not control in the management of the industry. I also think that our Institution should at once forsake its old policy of aloofness from the industry and take its proper place in leading us, without entering into controversial matters, in the desired direction. The old order has changed, and if competition between firms is, as it will be, reduced to a minimum, we might surely be prepared to give our knowledge and experience to the community through the instrumentality of Institution Meetings more freely and fully. I believe that if the Institution is prepared to act in this way it can play a great part in re-constructing the electrical industry on lines that will give it the successful future to which we all look forward.

# NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By A. P. Pyne, Member.

(*Address delivered 4 November, 1918.*)

Four years of war have now passed over us and have brought in their train many and startling changes in industrial conditions. Not least among these have been developments, actual or contemplated, in connection with electricity, which, having regard to the apathetic or deterrent nature of legislation in the past, would probably have been unattainable in this country for many years without the stimulating influence of the war.

The present trend of thought of our legislators is strikingly illustrated by an allusion, in a recent utterance of the Prime Minister, to the necessity for conserving our fuel resources, and to the probability of achieving this by the generation of electricity in bulk practically at the pit's mouth and distributing it to the consuming areas.

It is understood that the Government have under consideration the question of generation of electricity in bulk and its distribution over wide areas, questions which have largely been solved on the North-East Coast, from where, no doubt, valuable data have been obtained and utilized in the report prepared by the Coal Conservation Sub-Committee.

Progress is, however, by no means confined to generation and distribution, but is even more marked in connection with the application or utilization of electricity for numerous industrial purposes.

Such applications may be divided into three main categories, as follows:—

(1) The provision of driving power for large works' extensions and for enormous munition factories which have sprung up all over the country, and which it is hoped will ultimately be utilized for industrial purposes when the reconstruction period arrives. Hardly an engineering works of repute exists in the country that has not undergone some process of enlargement during the war, and has in consequence assisted in the creation of an enormous demand for electricity. The majority of such works, even though at present providing their own power, would benefit by a bulk supply at reasonably low rates. The application of electric power in these cases follows well-recognized lines and does not call for further comment.

(2) The creation of industries almost, or entirely, new to this country, and dependent on a bulk supply of cheap electricity for their exploitation on a large scale, as in the production of nitrogen from the atmosphere, and other chemical processes. With this group may also be included the electric furnace and the electrostatic method of removing suspended matter from gases. Such applications have mostly been developed in other countries; they may be said to be in their infancy with us, and certainly have not yet reached anything approaching finality.

(3) The driving by electricity of heavy machinery, plant, etc., previously associated with steam. Electricity may be said to be encroaching here on vested interests to a much greater extent than in the previous cases, and consequently development proceeds on somewhat different lines. Where steam has been used with success in the past, it will not always be easy to demonstrate that electricity can be used with still greater success. The most noteworthy examples of this class are electric propulsion of vessels and electrical driving of large rolling mills. The former has not yet been attempted on any very large scale in this country, but is being rapidly developed in the United States of America, where the application of the electric drive to battleships is already regarded as an assured success, the prime mover in this case being the steam turbine. It is possible that the success of the large oil engine for battleship propulsion, as foreshadowed by Sir James McKechnie some years ago, may be indirectly achieved on similar lines.

The development of the application of the electric drive to rolling mills is, however, proceeding rapidly in our midst at the present time, and the one or two motors of 8,000 to 12,000 h.p. installed within the last five years are already being overshadowed by machines of from 15,000 h.p. to 25,000 h.p. now under consideration, which, as far as we know, are as large as, or larger than, any plant of a similar nature existing in Germany, which country was, prior to the war, vastly ahead of us in the electrical equipment of rolling mills.

The adoption of such electrical plant in preference to steam in this country has been carried out in the face of considerable adverse criticism. Sufficient progress has, however, been made, and data collected, to enable us to estimate with precision the relative advantages and disadvantages.

The electric drive once decided on and the duty for which the mill is intended being clearly defined, then mechanical questions, such as most suitable motor size, torque, speed, etc., can be readily determined, partly by calculation, and partly from data obtained from Germany and elsewhere. It is to be observed, however, that the smaller the mill the more divergent does practice become. It is accordingly very desirable in the case of small mills to compare the calculated results with actual data obtained from a mill of similar size, when rolling the same sections as those contemplated.

When dealing with electrical questions, such as most suitable voltage, whether direct or alternating current,

or nature of control, a number of problems are introduced, depending on local conditions. Here, again, practice is more uniform in the case of large than in that of small equipments.

Motors for large reversible rolling mills are usually operated on the Ilgner modification of the Ward-Leonard system. The whole of the plant being placed in properly constructed and ventilated buildings is not subjected to the smoke and dirt inherent in a steel works, and consequently such standard practice can largely be followed in the general design and appearance of these machines, as is consistent with the heavy duty they are called upon to perform.

The mill motor must necessarily be of the direct-current type, of low speed, and capable of rapid reversals. It is usual to provide independent cooling by means of fans supplying filtered air.

The voltage will be as high as is consistent with good commutation.

The generator, or generators, of the Ilgner set will be designed for high speed and of corresponding voltage and capacity to the mill motor.

The driving motor of the Ilgner set may be designed for either alternating or direct current; if the latter is available in close proximity there is no objection to its use and it will be slightly more efficient than alternating current. Usually, however, local conditions will necessitate the use of alternating current, which allows greater latitude in the choice of voltage though not so much in that of speed.

The ratio of generator output to motor input will depend entirely on the nature of the output from the mill and may be as high as 7 to 1.

Should the mill be continuous running, the motor will preferably be supplied direct from the mains, seeing that only in the case of large motors requiring a wide speed range would the additional expense of a motor-generator be justified. If considerable speed variation is required, this can only be obtained by the use of direct current. By means, however, of special windings, or an arrangement of duplicate motors, two or more speeds can be obtained with alternating current. Generally speaking, a straight a.c. drive is simpler and preferable if speed variation can be dispensed with.

Large non-reversing mills requiring, say, 2,000 h.p. and upwards are generally direct driven, and smaller mills through gearing with a flywheel on the motor shaft. The cost of totally-enclosed machine-cut gearing is now so high that a low-speed motor and flywheel coupled direct to the rolls become a cheaper and simpler proposition. In cases where the speed or duty of the mill renders it difficult to obtain the necessary flywheel effect with a direct drive, a rope drive should have serious consideration; it is economical, and gives little trouble if properly installed, but requires considerable floor space.

The driving of rolling-mill auxiliary machinery by electricity has been more readily adopted in this country than has the electric driving of the actual mill itself, and in these minor drives greater divergence of practice is noticeable than in the case of the main machinery, particularly as regards the relative merits of alternating and direct current. Sufficiently diverse opinions are encountered from time to time as to make a discussion on the subject of some interest to those responsible for the selection, design, and upkeep of such plant.

Practice on the Continent has leaned towards the direct-current motor for rolling-mill auxiliaries, although as far as present information goes the use of the alternating-current motor is becoming more general. Much the same may be said of this country, where there is now a strong tendency to use, or at least to advocate, the use of, alternating current. It is to be remarked, however, that this tendency is more pronounced on the part of those responsible for electricity supply than on the part of those who have to use the motors. In America there appears to be a strong preference for direct current for all purposes requiring heavy starting torque, rapid acceleration, and frequent reversals, and for which a special design of motor is necessary. In a few works, where direct current is used for such plant, alternating-current motors of standard design are used for driving continuous-running plant, or machinery operating under less onerous conditions. As a general rule, however, the practice of using both a.c. and d.c. motors in the same works does not find much favour in America.

Generally speaking, it may be said that alternating current is not as convenient as direct current for furnace chargers, cranes, and similar hoisting machinery; it is, however, good enough, and where available should be used in preference to incurring the expense, losses, and upkeep of transforming apparatus. It should, of course, also be used for the continuous-running plant. It is in connection with the more exacting requirements previously referred to that the real differences of opinion exist.

There are many factors influencing a decision, apart from the inherent characteristics of the two types of motors, such as the degree of standardization permissible or obtainable with either type, ease of control, reliability, efficiency, nature of electric supply available (if any), and voltage.

In order to appreciate the problem properly, it is desirable to review the operating conditions and the steps that should be taken to meet these conditions.

Practically the whole of the following remarks will apply to all steel-works motors intended for the onerous duties under consideration. It is only proposed, however, to deal specifically with the electrical equipment for live rollers, skids, and screwing-down gears, these being representative of the severe conditions referred to.

The following tables give, in each case, the average of a series of observations taken under actual working conditions. They will serve to emphasize the severity of the duty.

Referring to Table 1, the principal features of this duty are the frequent reversals and the rapidity of acceleration. Live roller trains vary considerably in number, size and weight of rollers, and the motor fitted must be of corresponding horse-power, but the weight of the ingot, billet, or section, does not appreciably affect the load on the motor.

The duty here is somewhat different from that of

live roller gear; seeing that more time is available between operations, reversal is not so rapid, and when returning the skid the load on the motor is comparatively light. Heavy starting currents are, however, encountered, due to initial friction when skidding one or more bars from rest, and also to a possible attempt on the part of the operator to skid an excessive number of bars. Provision must be made for ensuring that the motor or gear shall not be damaged when a bar is skidded up against a heap of bars or other obstruction, thus bringing the skid suddenly to rest with current still on the motor.

The main feature of the duty in Table 3 is the short interval during which the motor is running, frequently amounting to "inching round" only. The usual practice is to screw down the top roll against the pressure of the balance gear. The load is therefore constant when screwing down and is very light; when raising

TABLE 1.

*Live Rollers.*

| No. | Live Rollers Size | Number of Reversals per Minute | Time from Full Speed to Full Speed | Maximum Input during Acceleration | Full Speed Input | Size of Motor fitted (1 Hour Rating) | Remarks |
|---|---|---|---|---|---|---|---|
| | Diameter Length | | Sec. | kw. | kw. | b.h.p. | |
| 9 | 1 ft. 6 in. × 3 ft. | — | — | 16·5 | 10·5 | 20 | 40 cwt. ingots |
| 20 | 1 ft. 6 in. × 7 ft. 6 in. | 6 | 6 | 46·9 | 32·3 | 50 | 6 in. × 6 in. billets |
| 14 | 1 ft. 6 in. × 9 ft. 7 in. | 9 | 7 | 52·4 | 39 | 50 | 12 in. × 3½ in. bulb angles |

TABLE 2.

*Skids.*

| Number of Skids Actuated | Number of Operations (out and back) per Hour | Time of each Operation (out and back) | Total Time Motor is Running | Time of Acceleration to Full Speed | Maximum Input during Acceleration | Full Speed Input | Kick when Bar comes against the Heap | Size of Motor fitted (one hour rating) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Sec. | Min. per hour | Sec. | kw. | kw. | kw. | b.h.p.* | |
| 2 | 15 | 24 | 21 | 0·7 | 27·6 | 20·8 | 37·2 | 20 | One 6 in. × 6 in. shell steel bar 14 ft. long |
| 2 | 12 | 28 | 21 | 0·9 | 23·5 | 19 | 26·2 | 20 | ,, ,, |
| 2 | — | 50 | 31 | 0·6 | 35·8 | 27 | — | 20 | Three 6 in. × 6 in. shell steel bars 14 ft. long |

* The motor is capable of exerting five times normal torque.

TABLE 3.

*Screwing-down Gear.*

| Number of Operations per Hour | Time taken by each Operation | Total Time Motor is Running | Maximum Input during Acceleration | Full Speed Input | Size of Motor Fitted | Remarks |
|---|---|---|---|---|---|---|
| | Sec. | Min. per Hour | kw. | kw. | b.h.p. | |
| 192 | 5·6 | 18 | 29 | 10·7 | 50 | 48 cwt. ingots to 6 in. × 6 in. shell billets |
| 216 | 6·2 | 22 | 26 | 16 | 50 | ,, ,, ,, |
| 216 | 6·4 | 23 | 22 | 15 | 50 | ,, ,, ,, |

the roll the motor may sometimes be rapidly reversed should the operator overshoot the mark. It is also possible to screw the rolls hard together, but this is unlikely to happen with ordinary care.

It will be gathered from the above observations that the time during which such motors are in operation varies considerably. In practice a heavy train of rollers may operate in each direction from 2 to 3 seconds only, with as many as 20 to 30 reversals per minute. On the other hand, when running bars, say to the saws or cooling banks, the time of each operation may be from 20 to 30 seconds, and reversals will only be necessary if the bar is carried too far and requires to be returned a short distance.

It may be also observed that the starting torque is frequently greatly in excess of the normal torque. Few of the motors are employed for more than very short intervals at a time, and the long pauses result in a comparatively light total or simultaneous load, amounting to about one-sixth only of the aggregate horse-power of the motors installed.

Motors for such drives are frequently placed in inaccessible positions, resulting in lack of attention; they are frequently subject to the effects of external heat, dirt, and exposure to the weather. The control gear is operated by an unskilled and rough class of labour, principally by boys. The actual running conditions involve severe mechanical shocks and stresses.

To ensure satisfaction, suitable reduction gear must be provided; this should have machine-cut teeth for the first motion, and preferably for the second motion also, running in an enclosed dust-type gear case, with shafts and bearings of very ample proportions in comparison with the normal horse-power to be transmitted. A satisfactory arrangement is to mount the motor and reduction gear on a cast-iron bedplate, which in the case of live rollers should be tied in with the line shaft driving the rollers, otherwise movement of the motor foundation may ultimately result in the final pair of gear wheels coming partly out of mesh.

Whatever the nature of supply or voltage, motors for the services indicated above must be totally enclosed and of especially robust construction. The machine should be split horizontally, and the magnet frame preferably hinged at one side to admit of removing and replacing a faulty armature or rotor in the least possible time. It is advantageous to make the outside of the machine symmetrical about a vertical centre, which entails bringing both ends of the armature or rotor shaft outside the casing and preparing them to take a pinion or half coupling, the feet and holding-down bolts being arranged symmetrically as regards the shaft ends. Should one end be damaged, the motor could be reversed on its foundation and the opposite end used for driving purposes.

The insulation material should be the best obtainable and consist wherever possible of mica or micanite. Special attention must be given to the method of attachment of windings to commutator lugs, to binding bands, and to the securing of the core plates and commutator to the shafts.

The shaft ends could with advantage be provided with two keys, machined out of the solid.

Most of the above general requirements will be found embodied in the rolling-mill motors constructed by several of our leading manufacturers.

As the operations in a rolling mill take place in regular sequence, it follows that the stoppage of a single motor may lay a whole mill idle, with resultant heavy financial loss; consequently, in the event of a breakdown the faulty apparatus must be replaceable, entirely or in part, in the shortest possible time.

The recognition of the necessity for a special type of motor for rolling-mill auxiliaries, and the extent to which these motors are coming into general use, make a considerable measure of standardization highly desirable.

The user and the manufacturer will approach this subject from slightly different points of view, seeing that the former will be concerned with his own works only but the latter must cater for the needs of the industry as a whole. The user, before placing an initial order, should satisfy himself as to the degree of interchangeability obtainable between different motors or parts of motors of the same size; he would also be influenced by the prospect of obtaining replace parts from the maker's stock at a later date. It would further be of considerable advantage to the steel-works manager if he were able, in case of necessity, to substitute a motor by another maker. To meet this requirement it would merely be necessary to standardize such features as the half coupling, the holding-down bolt holes, the vertical distance from the centre line of the machine to the bottom of the feet, and the horizontal distance from the coupling face to the holding-down bolts.

It will follow from the above that the motors of any one size used in any particular works should be interchangeable, and the number of such sizes kept within small limits. The attainment of this object is facilitated by the fact that high efficiency is of secondary importance, and must give place to reliability and rapidity of replacement, which therefore permits of the selection, for a given duty, of a motor of somewhat larger size than would be considered good practice in normal commercial work. It may further be pointed out that in some instances, such as for long trains of rollers, it is advantageous to use two small motors working in unison, in preference to one large one, which may be of considerable assistance in keeping down the number of sizes.

The following table is taken from an actual rolling mill. The columns headed 1 and 2 show, for purposes of comparison, the sizes proposed by two of the firms originally tendering for the installation; the next column shows the size of motor actually installed; and the final column the average horse-power actually developed.

It will be seen that two sizes of motor only are in use, and this without excessive first cost, or undue effect on the efficiency. Where the use of these special motors is extended to cranes, and where mills of various sizes are to be found in the same works, then some extension of the number of sizes is desirable, but in all except very exceptional cases it will be feasible by judicious arrangement to ensure that four sizes should not be exceeded.

The relative merits of alternating and direct currents

TABLE 4.

*Schedule of Motor Requirements for Typical Mill.*

| | | Brake Horse-power of Motor | | | |
|---|---|---|---|---|---|
| | | Proposed | Proposed | As fitted | Actually taken |
| | | (1) b.h.p. | (2) b.h.p. | (3) b.h.p. | (4) b.h.p. |
| Approach rollers | No. 1 | 68 | 190 | 50 | 56 |
| ,, ,, | No. 2 | 68 | | 50 | 41·8 |
| ,, ,, | No. 3 | 68 | 160 | 50 | 49·6 |
| ,, ,, | No. 4 | 68 | | 50 | 53 |
| ,, ,, | No. 5 | 68 | 160 | 50 | 47 |
| ,, ,, | No. 6 | 68 | | 50 | 48·7 |
| Long rollers | No. 1 | 33 | 30 | 50 | 50·8 |
| ,, | No. 2 | 33 | 30 | 50 | 46 |
| ,, | No. 3 | 52 | 50 | 50 | 49 |
| Return rollers | .. | 52 | 50 | 50 | 51 |
| Short rollers | .. | 20 | 20 | 20 | 20·4 |
| Screw-down gear | .. | 20 | 20 | 50 | 21·4 |
| Skid .. .. | No. 1 | 20 | 20 | 20 | 19·5 |
| .. | No. 2 | 20 | 20 | 20 | 22·2 |
| ,, | No. 3 | 20 | 20 | 20 | 21·3 |
| ,, | No. 4 | 20 | 20 | 20 | 18·5 |
| ,, | No. 5 | 20 | 20 | 20 | 20·3 |

affect very slightly the question of standardization. It may be pointed out, however, that the manufacture of motors by one maker, which will be mechanically interchangeable with motors by another maker, is commercially feasible with d.c. motors if the existing proportion between direct current and alternating current is maintained, but there would be very little prospect of makers so standardizing a.c. motors.

If, in the near future, the use of a.c. motors increases considerably, then it is unlikely that such standardization of even d.c. motors will be realized.

With the conditions of operation clearly before one, the relative suitability of alternating and direct current to fulfil these conditions can then be considered.

A few years ago it would have been said that the three-phase induction motor was more reliable than the direct-current machine, which suffered from frequent commutator and brush troubles. This may still be so with squirrel-cage motors, but wound rotors are necessary for the duty under consideration and these machines are not without troubles of their own. The winding as a whole is not as simple as that of a series-wound d.c. machine, and repairs are more difficult to carry out, owing to the form of slot usually employed for induction motors. In view of improvements effected in direct-current motor design during the last few years, there is not much to choose between these two types on the score of reliability, and if we also take the starting or controlling gear into consideration, then the balance is perhaps slightly in favour of direct current.

The principal characteristic of the d.c. series motor, namely, its capacity for exerting a large turning moment at low speeds, is a valuable asset in connection with this work, and enables such motors to deal with very heavy overloads for short intervals. This feature is not shared with the a.c. machine, which is liable to drop out of step and pull up under similar conditions. It must accordingly be made of a larger size to achieve the same results.

The starting current of the induction motor is heavier than that of the d.c. machine, and the power factor is adversely affected thereby. Whilst this is of small importance for continuous-running machines with infrequent starts, it must be given serious consideration when frequent starting and reversing forms part of the normal duty. As a slight offset against this, it may be pointed out that if the motor is "stalled" the maximum current that can pass will be limited in the case of the induction motor to an amount that will prevent any serious damage being done to the machine; the d.c. motor under similar circumstances would have to rely solely on its protective switchgear.

The relative flexibilities of the two systems affect principally the motor and the transmission, including transforming apparatus. With regard to the motor, if direct current it may be series, compound, or even shunt wound with saturated field. The two latter admit of the armature being short-circuited with or without resistance, and thus used as a brake; a very useful attribute for certain special applications where precision of control is essential. No such variations are possible with the a.c. motor.

On the question of speed variation there can be no two opinions; a much wider range, and with greater efficiency and simplicity, can be obtained with the d.c. motor than with the a.c. motor.

Transmission by alternating current is more convenient, both as regards voltage and transformation, than direct current, which necessitates the use of rotary apparatus with its consequent upkeep and additional possibility of breakdown, its sole advantage lying in the facility with which the voltage may be modified within certain limits without interfering with supply.

Whilst the efficiency of a static transformer is higher than that of a motor-generator or rotary-converter equipment, a steel works generating its own power would not necessarily require to use transforming apparatus. In any case, taking the system as a whole under the operating conditions previously enumerated, direct current will be found to be considerably more efficient. To ensure reliability in the a.c. motors under discussion, a considerably larger air-gap than is usual must be provided, resulting in a very low power factor.

Size for size the a.c. motor will be considerably heavier and more expensive.

Apart from the considerations enumerated above, it will be obvious that the successful operation of either d.c. or a.c. motors will depend largely on the voltage, method of control, and nature of switchgear.

The question of voltage is one affecting the three-phase motor to a much lesser extent than the d.c. motor, and it would no doubt be quite feasible to adopt 2,750 volts for three-phase motors of 50 h.p. and upwards, without decreasing the reliability of the switch-

gear, although the arduous nature of the service under review renders it inadvisable to go to so high a figure. On the other hand, the d.c. motors and their switchgear, operating under these special conditions, become exceedingly troublesome at pressures much above 240 volts unless considerable care is exercised in selecting the most suitable method of control and type of switchgear. Not only is the roughest class of labour obtainable used for operating such switchgear, but any suggestions on the part of the electrical department that a reasonable amount of care should be used by the operator would be unsympathetically received by the mill manager, who would consider that if electrical gear is not "fool proof" it should not be used; consequently, the human element must be eliminated as far as possible, and the operator should only have to decide when a motor is to be started up and in what direction. Some form of automatic starting apparatus is clearly necessary that will permit of acceleration at a predetermined rate, which must be as rapid as possible without damaging the motor, and which must take place independently of the operator.

Magnetically operated switches, known as contactors, have been developed to cope with the above conditions, which they do very satisfactorily. A contactor equipment comprises a master controller of robust proportions, reversing contactors, and resistance contactors. The former operates first the main or reversing contactors to give the motor the desired direction of rotation. The resistance contactors then close in sequence, cutting out successive steps of resistance at a predetermined rate. The master controller carries only the operating current of the contactor solenoids; it is usually provided with two or three speeds in either direction, obtained by controlling the actuating coils of the resistance contactors. This system lends itself to the addition of various refinements, such as braking contacts, arrangements for limiting the travel of the plant, overload and no-volt release trips, and others of a similar nature.

For direct current, contactor gear may be said to be the most suitable and reliable form of switchgear, its superiority over the usual types of ordinary switchgear being such that one might say the success of the live-roller motor is largely attributable to it. Contactor gear applied to alternating current is not so simple, nor is its superiority over other forms of alternating-current switchgear quite so marked. At the same time it is well worth adopting this type of gear where more than one speed is desirable. If, however, it is only desired to run the motor at full speed in either direction, then the eddy-current starter, as applied to slip-ring induction motors, appears to possess superior attractions. The eddy-current starter utilizes the reactance of the alternating-current circuit. Assuming current to be switched on a three-phase motor, but with the rotor at rest, the frequency in the rotor circuit is that of the supply, and the voltage is at its maximum. As the rotor accelerates, the frequency and voltage of its circuit decrease, both being proportional to the difference of speed between the rotating flux in the stator and the speed of the rotor. The starter consists of low-resistance coils, wound on iron cores, so that the external circuit of the rotor consists as nearly as possible of reactance. The starter generates comparatively high electromotive force in opposition to the rotor voltage. As the rotor speeds up, this E.M.F. gradually diminishes; but as the frequency of the rotor circuit also decreases, the starting current remains practically constant. The power factor of the apparatus is about 0·8, and consequently the starting torque is comparatively high.

The principal advantage of this type of starter is its simplicity and the protection it affords the motor. Thus, if the motor is frequently stopped and started, the apparatus can be left permanently in the rotor circuit. It can be combined with a contactor for short-circuiting the rotor if the motor is continuous running, or with a reversing contactor if the motor is required to be reversible.

This type of starter will accelerate the motor more rapidly and with greater efficiency than a resistance starter with the same starting current. The stator current can be reversed with the motor running at full speed without any injurious effects, seeing that even at the moment of reversal the rotor current cannot exceed the starting current, which now acts as a brake until the rotor is brought to rest, when it will at once be accelerated up to full speed in the opposite direction. When the apparatus is designed for starting the motor up against a fixed starting torque, should this torque be exceeded the motor will immediately slow down until the overload is removed, when it will automatically start up again. It will be obvious that starters of this type, designed with a view to reliability, will have many applications in a steel works.

The foregoing remarks, relative to the respective merits of direct and alternating current for rolling-mill auxiliaries, may be roughly summarized as follows:

If direct current is available, it should certainly be used in preference to obtaining a special supply of alternating current; but the higher the voltage the more essential does it become to give especial care to the switchgear, which should be of the contactor type for reversible motors. If alternating current only is available, it will usually be found advantageous to install rotary converting apparatus for the provision of direct current for a certain number of motors, unless the nature of the drives lends itself to control by the eddy-current apparatus.

## Discussion before the North-Eastern Centre, 4 November, 1918.

**Mr. C. Petersen:** In view of the difference of opinion amongst steel-works engineers as to whether a.c. or d.c. motors should be adopted for the driving of auxiliary plant in steel-works, the Chairman could not have chosen a more suitable subject for his address. From the manufacturing point of view, a debate on this subject is particularly welcome as it tends at any rate to point to the direction of the future market for

such plant. Where the supply is alternating current, the temptation is of course to adopt a.c. plant throughout and thus avoid a mixed system, and there is no doubt that this has been the deciding factor in many instances where a.c. plant is installed. In these days, however, of intensive production, other considerations such as economy of time must be taken into account, as well as simplicity of operation, bearing in mind that the output of a steel works is as much dependent on the rapidity of handling of the metal by the auxiliary plant as on the capacity of the main rolls. I think that all engineers who are conversant with the characteristics of the two types of machines are agreed that for rapid and accurate handling the d.c. motor is the better of the two. Comparative tests have been made from time to time, and it has been found in some cases that, in order to obtain the same rate of acceleration and the same rate of handling, the a.c. motor had to be approximately 40 per cent larger than the d.c. motor, due to the difference in torque characteristics. In crane operation, the disadvantages of the a.c. motor are particularly apparent, there being no possibility of using dynamic braking or any of the slow-down schemes common to d.c. machines. I think that as far as control is concerned, for the operation of lifting tables, manipulators, and other machines about the mill, the a.c. motor is at a disadvantage. It is, of course, only experience in this class of work that can reveal the true state of affairs, and it is therefore interesting to note that in America, where both types of machines have been given a fair trial, most of the steel-works engineers are in favour of the d.c. motor. About the year 1908, a.c. auxiliary motors were installed at the Gary Works in America, the engineers being of the opinion that the a.c. auxiliary motor presented such advantages over the d.c. machine, from the standpoint of operation and power distribution, as to warrant such a step. The machines, I understand, were given a trial lasting over several years, but the results did not come up to expectations, the rate of handling not being sufficiently rapid to meet the great outputs demanded from American steel works. I believe that throughout the steel works of America at the present time the d.c. motor is almost universally adopted. It is not necessary to dwell on the low power factor of the a.c. auxiliary motor, as this is sufficiently recognized, and, as far as overall efficiency is concerned, I do not think there is much to choose between the two systems, even after taking into account the conversion losses from alternating to direct current. Regarding the question of voltage, there seems to be a difference of opinion at the present moment as to whether 250 volts should be the limit or whether a higher voltage can be safely adopted. Considering the conditions which generally exist in steel works, I do not think the insulation can always be depended upon for protection, and, as the men must work so much around the auxiliary motors, I think it is wise to keep the voltage down.

**Mr. C. T. S. Arnett:** With reference to the saving of money and coal in steam as against electricity, it may be of interest to recall that from tests I carried out some years ago at several rolling mills in the United Kingdom, it was found that the average saving by using electricity was 6d. per ton of steel, with coal at 19s. With regard to the space required for rope drives, I may say that in the case of a recently installed mill this drive has been adopted, and whilst it has proved efficient and satisfactory it took very little more room than gearing. Since a gear drive projects nearly as much beyond the end of the pinion housing as the rope wheel does, and the ground each side of the gear drive for some considerable distance is dead ground, there is therefore not much gained in ground space by gear drive as against rope drive. Referring to the necessity for a variable-speed motor on a main drive for a mill, I would say that a firm would be quite justified in installing a rotary and d.c. variable-speed motor of 700 b.h.p. for the finishing stand of an 18-in. section mill. I have found the ordinary one-hour-rated open-type standard a.c. motors very efficient for roller gear, and I do not ask for large air-gaps except for small motors. The only parts of the motor which cause any trouble are the bearings. Men were employed to test the air-gaps once a month. We have in use 100-h.p. motors which are reversed 19 times per minute, and the maximum horse-power demanded of these motors is 3·5 times the normal rating of the motor, and there have been no breakdowns due to shafts breaking or to coils burning out, except when bearings have failed and the rotor has touched the stator, during the last 5 years. From tests we have made, the maximum pressure generated in the rotor on reversal is 1,200 volts. On some motors I have also found alternating current for crane driving very efficient, and we have no idea of changing to direct current. With reference to having two motors fully loaded on live roller gear, I am of opinion that it is better to have two motors, each of which is capable of dealing with the rollers, so that in the event of one breaking down, the other is left to deal with the work. As regards the screw-down motors, I think a 50-h.p. motor is too light and that 75/100 h.p. is necessary on a 40-inch cogging mill. I should like to have the author's opinion as to whether an eddy-current controller would be suitable for a screw-down motor.

**Mr. H. C. Booth:** The polyphase commutator motor is made with shunt and series characteristics and has proved very efficient. I think that the eddy-current controller has brought alternating current into line with direct current so far as speed of operation is concerned. That is to say, acceleration, retardation, reversal, and re-acceleration can be obtained with the a.c. motor and eddy-current controller as quickly as, if not more quickly than, with the d.c. motor and contactor gear, and on reversal the braking effect with the eddy-current controller gives a retardation of something more than twice in bringing the motor to rest, before actual reversal of direction of rotation takes place.

**Mr. S. Thompson:** With the great advance that has been made in the design of both d.c. and a.c. motors for steel-mill service, the question of reliable control gear is very important. The simpler and more reliable

it can be made, the better. I do not agree with the author's statement with regard to a.c. contactor gear not being so simple as d.c. gear. The a.c. contactor unit has lately been greatly improved, and I think is capable of standing up to very heavy service equally with the d.c. gear. It is possible to get satisfactory current relay control for reversing a.c. contactor gear similar to direct current. Alternating-current controllers have the advantage that fewer steps are usually required for most applications than would be required with d.c. gear. The chief advantage of the eddy-current starter lies in the fact that it gives complete protection to the motor, its construction is very mechanical, and since it has no moving part it can be stowed away in less accessible positions, frequent inspection not being necessary. When placed in a damp position the starter can be placed in an oil tank. The eddy-current starter operates satisfactorily as a slip regulator.

(*Communicated*): Mr. Pickett's remarks are somewhat misleading. One of the chief advantages of the eddy-current starter is that when starting from rest, and when reversing at full speed, the motor takes the shortest possible time—shorter than a resistance starter—but the torque is produced in such a manner as to reduce the shock on the machine drive to less than that produced by the slower acting resistance starter. An a.c. motor operating with an eddy-current starter may be said to have a characteristic very similar to a series d.c. machine, which, as Mr. Pickett says, is ideal for most steel-mill drives. The eddy-current starter as supplied is capable of starting and stopping the motor as frequently as the operator can manipulate the master controller. The construction of the starter is such that the heat produced in the iron is got rid of without affecting the coils, which are specially constructed and not wound on the iron cores. They are capable of long service without any signs of deterioration. For certain applications the whole starter is immersed in a sealed oil tank, all cable connections being made through special glands, thus making it possible to install the starter in the very worst positions. Mr. Pickett's remarks regarding a new induction starter are interesting, because so many starters of this type have been designed and have never proved successful. Without any details it is impossible at present to criticize it, but there is only a small field in the more important steel-mill services for a non-reversing starter. Regarding the cost of contactor control, the price of a.c. gear is very little higher than d.c., and if the higher voltage possible with alternating current is compared with 220-volt d.c. the prices are in favour of alternating current. Regarding series-current relay control, the result of long experience does not show that the relay interlock is specially subject to trouble. Interlocking is the easiest requirement to meet, and the other requirements of wide range and ease of adjustment with great accuracy in operation are very important. In these respects the latest design of series-relay interlock is highly efficient, and gives almost perfect protection to the motor.

**Captain A. H. Law**: I am afraid I have no practical experience of the relative merits of the two classes of motors under consideration when applied to rolling-mill conditions, but it seems to me that the difficulty referred to by one or two speakers in connection with the periodical testing of air-gaps could be overcome by the provision of testing planes in close proximity to the shoulders of the shaft; in this way any wear of the bearings which might reduce the air-gap clearances could be detected without dismantling the motor. Somewhat similar methods are used in steam turbines to detect wear on bearings and consequent reduction in blade clearances.

**Mr. G. A. Roberts**: From the author's remarks and the discussion following, it seems that d.c. motors are favoured for rolling-mill equipment, and I entirely agree on this point. The chief consideration of mill managers is reliability. The breakdown of a single motor often holds up the entire mill; initial cost is therefore not considered where extra reliability can be obtained. In addition to other points discussed, a.c. motors mean more wiring and more complicated switchgear, and therefore greater risk of breakdown. Considerable improvement could be made in d.c. motors by doing away with binding wires on that portion of the armature which comes under the pole-pieces. The maintenance engineer often obtained false readings when taking the clearance in the air-gap, due to the copper clips used in fastening the binding wires standing above the remainder of the band, causing serious damage to the armature when these clips foul the pole-pieces. Manufacturers often send enclosed a.c. motors out with no provision for taking the air-gap clearance. Enclosed motors generally would be much easier to maintain if greater attention were given to this point. Inspection covers might be fitted to the driving end of d.c. motors to obviate the inconvenience of working feelers past the brushgear from the commutator end. Trouble is often experienced too, due to the carelessness of makers in not drilling bolt holes strictly to templates, even in their standard motors. This is a fault which managers and mechanical engineers can understand. The impression given is that the electric motor has still not had that attention which is essential to reliability, serious losses being at times experienced through stoppages owing to standard motors not being interchangeable.

**Mr. A. Davidson** (*communicated*): My remarks will be confined to the vexed question of a.c. versus d.c. motors for rolling-mill auxiliary equipments. There is no doubt that the advent of power companies' mains, and the development of the steam turbine generating high-voltage electrical energy in private stations, have had much to do with the introduction of alternating current in steel works. Many years of progress had been made with the d.c. auxiliary motor before the advent of this latter development, but to-day I believe the claims of the a.c. motor are at least well worth very serious consideration. In regard to the advantage (if any) between the two systems for mill auxiliaries, after extensive practical experience my opinion is that there is very little to choose between them. Undoubtedly when fine speed adjustment is necessary direct current has advantages, but taking the steel-works requirements as

a whole I think the advantage lies with alternating current. Two good points in favour of the latter are the absence of a commutator and the higher safe voltage permissible. A great many a.c. troubles in connection with auxiliary mill motor-drives have been due to the want of a suitably designed motor. Years ago it was found that the usual standard commercial type of d.c. motor was absolutely useless for work of this description; after which the heavy railway or similar type of machine was introduced, which undoubtedly got clear of many previous troubles. The same applies to alternating current. Motors of more or less standard design were at first put forward, with disastrous results, until to-day we see the advent of the special a.c. live-rolls motor, built on similar lines to the d.c. machine and operating most successfully. One important change in design which was found to be necessary, and one which rather horrified the electrical designing engineer, was the question of rotor clearance. It is most important that this be kept as large as possible —say 0·1 inch for motors of 75/100 h.p. This allows a reasonable bearing wear and long running life of motor. On the other hand, of course, the power factor is reduced; but when one bears in mind the number of starts per hour to which machines of this description are subject and the time allowed for acceleration, it will readily be seen that the power factor does not call for any very serious consideration. The efficiency of the drive must not be considered as a case of individual efficiency of each particular motor, but rather one of general efficiency as measured in continuous operation and therefore output of the mill. From an upkeep point of view my experience is that there is little to choose between the two systems. The slip-rings are, however, much to be preferred to the commutator. On the other hand, winding repairs are rather more difficult to carry out on a.c. machines. For the control of mill auxiliary motors, owing largely to the class of labour employed, it is impossible to get good results from any type of hand control. The contactor type of control gear has of late years largely superseded the ordinary controller, and excellent results have been obtained, but owing to the cost and complicated nature of these gears much still remains to be done. The later eddy-current type of control gives promise of being highly successful, but personally I look forward to the development of the special short-circuited type of motor, with its simple form of control gear. One has only to consider the time permissible to accelerate motors for drives of this description—in many cases less than one second being allowed—to realize how little chance there is of getting any useful benefit from steps of resistances, etc. I heartily agree with the author as to the desirability of keeping the types and powers of motors down to a minimum. Great difficulty is, however, experienced in obtaining anything like satisfaction on the point, largely owing to the manufacturers continually changing designs, and also to the great diversity of design between different makers. Largely owing to this fact the attention of many of our large steel manufacturers is, I believe, being turned to the question of manufacturing a standard line of motors for themselves. With the modern up-to-date machine-shops which the steel maker is now equipped with, this would offer no difficulties whatever, and would undoubtedly possess many advantages.

**Mr. W. C. Mountain** (*communicated*): The information the author gives in connection with the power required to operate live-roller gear is extremely useful, but I think it would be a little more complete if he gave the size of ingot or bloom dealt with in the various operations, and also possibly the weight and the revolutions per minute at which the live rollers are running. The main object of the address is to create a discussion on the relative advantages of d.c. and a.c. motors, particularly for operating live rollers, skid, and screw-down gear, all of which demand motors capable of rapid reversal, of special robust construction, and suitably protected to withstand exposure and the dust and dirt of steel works. Many of the illustrations show arrangements which are exceedingly cramped, and where I think considerable improvements might be readily made by designing the drive in such a way that the motor can be readily got at, if required, instead of being placed in the most inaccessible and difficult positions. It is interesting to note that the author expresses a distinct preference for d.c. motors. This is confirmed by Mr. Petersen, but a directly opposite opinion is expressed by the very concise remarks of Mr. Arnett, of Messrs. Bolckow, Vaughan & Company. About 12 years ago I designed a rolling-mill equipment for a steel works in South Wales, in which d.c. motors were used for driving the live-roller gear, etc.; and although these motors were of very much stronger construction than the ordinary type of machines, I came to the conclusion that for this class of work something exceptionally well protected was required. I am also able to confirm the author's remarks that in any type of gearing it is necessary that the whole should be strongly tied together, preferably by a bedplate, so that there is no risk of the gearing being pushed out of gear by the foundations or attachments giving way. As the driving of this class of work has progressed, the necessity for not only a very massive and well-protected type of motor, but also an improved type of switchgear, has become very apparent, and I am inclined to think that the real preference for direct current to which the author referred has arisen principally from the fact that there existed on the market a tramway type of motor which seemed to possess the massive and well-protected features required, whereas makers of a.c. motors had not yet grasped the problem. Personally, I must confess to having a very strong feeling that three-phase motors for 440/500 volts, suitably designed for the duty, would not only be simpler but would be very much more robust as regards construction than any d.c. motor can be with its commutator and brushgear, and that a motor of the three-phase type would require very much less attention and consequently less cost for upkeep. There is no doubt also that by adopting the higher voltage very considerable economy can be made in the cost of cables and also, I think, in the switchgear, as the current to be dealt with will be only half what it would be with a lower pressure of, say, 230 volts. I am also inclined to think that a motor

of the "cascade" type, as designed by Mr. Hunt of the Sandycroft Company, which is really a simple squirrel-cage motor without slip-rings, but with a specially wound rotor and with tappings on the stator, would lend itself to this class of work exceedingly well. I know from actual experience in operating underground haulage gear at collieries, where the work is very similar, that this type of motor has proved most satisfactory. Dealing with the question of motors driving rolling mills, it would be very interesting to know what wear and tear has taken place on the commutators of heavy d.c. rolling-mill motors, and also what is the cost of upkeep for brushes, etc. A day will come when the very expensive and massive commutators used on rolling-mill motors, and also all d.c. motors about rolling-mills, will have to be replaced; and I am afraid that the expense of replacement and the very considerable delay which must necessarily occur in taking off and putting on a new commutator will entail very costly and lengthy stoppages, unless of course spare armatures complete with commutators are kept available. This problem is one which requires consideration, and if, in the development of a.c. machinery, main rolling-mill motors can be designed with all the existing advantages of d.c. motors, a very great problem will have been tackled and one which will go a long way towards the advancement of rolling electrically. I was hoping that the author would be able to give some actual results of horse-powers upon the main rolling-mill motors with which he has been associated when rolling ingots and blooms of various dimensions. There appears to be very little information upon this subject at the present time, except what comes from Germany. It would also be greatly to our advantage to have some reliable figures of the consumption of current per ton rolled, both in cogging and finishing mills, obtained from British mills, and I hope that some member, or members, of the Institution will at an early date give this information in a practical concise form, when I am sure if results are commercially satisfactory it would help very much towards the further advancement of this work. I was interested to hear Mr. Walker's communication respecting the introduction of a.c. motors for shipyard use. My late firm were, I believe, one of the first if, not the first, to introduce three-phase motors for use in mines in this country, this installation being for the Tredegar Coal Company in South Wales, where the three collieries, Pochin, Bedwellty and Ty Trist, were all coupled together and electrified. This work was done some 20 years ago, and the motors and generators were supplied by the Oerlikon Company of Switzerland.

**Mr. F. N. Pickett** (*communicated*): I am in complete agreement with the author on his general conclusion with regard to the advantages of d.c. apparatus for the auxiliary drives in steel works. The characteristics of the d.c. series-wound motor would appear to be ideal for such services as live rolls, screw downs, skids, and most certainly for cranes and charging machines. It more nearly reproduces the conditions and characteristics of hydraulic driving, and for this reason alone will appeal to the mill men. It appears impossible to reproduce the same characteristics with a.c. motors, and there always seems to be a great deal of uncertainty as to the ultimate performance when three-phase motors are installed. The modern d.c. mill motor is undoubtedly a wonderful engineering feat, with its extraordinary capacity for withstanding overloads and abuse, and it is to be hoped that British manufacturers will devote some of their energy to its development in this country, as the majority of the d.c. mill motors in use to-day are of American origin. The author mentions that American practice is all in favour of d.c. motors. He might have gone further and pointed out that very rarely is a higher d.c. voltage than 220 volts used in American steel works for auxiliary apparatus. The claim is, I believe, that increased reliability is thus obtained, the general opinion being that insulation cannot be made to withstand the severe services at higher voltages. With regard to control gear, in which I am personally more interested, there would appear to be further advantages for d.c. drives. I assume, of course, that there is no argument as to the necessity for the use of contactor gear in the control of steel-works motors of anything over 20 h.p. The first cost of a fully automatic d.c. contactor panel is much lower than for the corresponding a.c. type. The increased cost of a.c. over d.c. control is probably 75 per cent. The refinement of control with direct current is undoubtedly greater than with alternating current. On live-roll drives one can provide a "checking point" to take the shock off the gears when the motor is brought to rest by plugging. It should be realized that it is possible to twist off shafts and to smash teeth on the gears without some such provision. This brings out one of the disadvantages in the use of the so-called eddy-current starters, which must be wound to allow rapid acceleration of the motor, so that should the motor be "plugged" the stopping is very violent. On the other hand, should the starter be wound to provide against the violent effect, then the normal acceleration of the motor is too slow for steel-works practice. The usual form of eddy-current starter with its solid core appears to suffer from overheating. The solid core provides excellent heat storage, and as the windings are wound direct on the core sooner or later they suffer. A newer form of starter known as an induction starter with automatic acceleration and no moving parts has overcome the overheating difficulty by removing the winding from the proximity of the secondary where the heat is generated, and this starter will probably have a field where rapid reversals are not required. A further advantage of d.c. contactor control is due to the elimination of series relays with their small posts and discs, which are troublesome and difficult to keep in order. It is possible to-day to obtain shunt-coil contactor panels with a magnetic lock-out to secure correct acceleration of the motor (these contactors must not be confused with the series-coil lock-out switches, which are plain starters). This form of control eliminates once and for all a portion of contactor gear which has long been open to suspicion and where probably 75 per cent of faults have occurred, namely, on the posts and discs of series relays and interlocks. In conclusion, a plea might be made

for standardization of control gear in a similar manner to that proposed by the author for motors, namely, the number of steps, the type of master switch or master controller, enclosure and rating of resistances, etc.

**Mr. H. Walker** (*communicated*): I propose to make a few remarks on the historical aspect, which I think will show that alternating current has, to all intents and purposes, had equal opportunities with direct current, at any rate on the North-East Coast. The Tesla patents were taken out in 1888, and these covered both multiphase generators and motors. Up to 1895, machines of this type had not been introduced into this country, except in a very small way indeed. In 1895, however, I was in Baden and went over the works of Messrs. Brown, Boveri & Company, and we began to go into this question after this visit, but found in 1896 that the Tesla patents were vested in the British Westinghouse Company in this country. We therefore took from them the licence for the manufacture and sale of these machines, and I think we were about the first firm in this country to do so, and to undertake manufacture apart from the Westinghouse Company themselves. In 1897 we supplied a 100-k.v.a. generator to Messrs. Palmers' steel works, also about 20 motors varying from 20 to $1\frac{1}{2}$ h.p., which were driven from this machine. These were of the two-phase type, as three-phase had not then been brought into use. In 1898 and 1899 we supplied the North-Eastern Steel Works, Middlesbrough, with 77 motors. These were for two-phase also, on 250 volts and 40 periods. The motors ranged in output from 60 to $1\frac{1}{2}$ h.p., the total horse-power being about 1,200. In 1899 we obtained the contract from Messrs. Palmers to fit up the installation for electric driving throughout the whole of the engine works and shipyard, and it was arranged that we should join the British Westinghouse Company in this work, which was divided between us, the Westinghouse Company supplying the main generators and some of the motors, and we supplying the remainder of the motors and all the installing work. The Chairman will be fully conversant with all that has been done in that respect. This installation was carried out as a three-phase system, as by this time the advantage of three-phase over two-phase was realized, and from that time onwards the three-phase system has entirely held the field, although at the North-Eastern Steel Works the two-phase system is still in use. Since this date we have supplied other three-phase machines for power-driving in various shipyards throughout the country. We made several attempts to get the three-phase system introduced into mines about that time, but were not successful in doing so. On one occasion I saw a very important mine manager with a view to introducing three-phase driving into his pit, but he showed me an engine which was working down the pit and was supplied by steam from the surface, and which he said had run without a stop for 105 years. He asked if we were in a position to show a three-phase motor which had run without a stop for the same period. As this was a condition somewhat difficult to comply with, and as no other argument would convince him of the advantages of three-phase work, we accepted his statement of the fact that the engine had run 105 years, and no business resulted. Some years after this manager died and the three-phase system has since been introduced into the pit.

**Mr. W. W. Wood** (*communicated*): Whilst direct current has advantages over alternating current for certain classes of steel-works plant, I am of the opinion that alternating current (preferably three phase) will be increasingly used in the future. The large areas now covered by the leading steel works and the large amounts of power needed, favour high-tension a.c. transmission. The probability that steel works generating all or part of their current will link up with other works and with supply companies' networks, also favours the use of alternating current for the steel-works drives, because the interconnections must be high-tension alternating current, and the use of a.c. motors will save the extra capital expenditure, depreciation, maintenance, and higher losses of rotatory converting machinery as compared with static transformers. Whether it pays better to drive all the works electrically or to use steam for, say, the cogging mill, and the exhaust in a mixed-pressure turbine generating electricity for use on other mills, appears to be a disputed point at present, as some engineers claim the latter arrangement gives better commercial results if all factors are taken into account. Where exhaust steam is used the three-phase turbo-generator is much cheaper than the geared d.c. machine, and in most cases more economical. This again favours alternating current. Many engineers favour the adoption of gas engines to utilize blast-furnace gas where this is available, and here possibly d.c. generators may be favoured on account of easier parallel running, but there appears to be no great difficulty in using alternators even in this case, and certain firms are installing such machines. As regards the use of alternating current in the works, the motor-generator sets for large reversing mills appear to be invariably driven by three-phase motors, although, as the author points out, direct current (presumably on the booster and reducer principle) would give a higher efficiency. It would appear, therefore, that the relative positions of generating plant and mill generally make alternating current commercially the best. Where it is possible to avoid using the reversing mill and drive with a constant-speed motor running in one direction, the electrical plant will be very considerably cheapened and the efficiency increased, as the losses in the motor-generator are a considerable percentage of the total used; 30 to 40 per cent loss is quite usual. An interesting example of such a case is the use of a three-phase induction motor of 3,000/6,000 h.p. which is at present being put in for driving a plate mill at a leading steel works. The plate mill is of the three-high type, and the motor is coupled to a high-speed fly-wheel storing a large amount of energy, the drive to the mill being taken through gearing. The non-reversing mill is often used for a variety of sections, thus needing a variable-speed motor. For this direct current is often necessary, and if so a rotary converter placed close to the mill can be used, the converter being designed to take a large leading wattless current and improve the general

power factor. It seems to me, however, that it would be better commercially to specialize the work rolled on each mill and consequently get a much bigger output from it, and at the same time enable a constant-speed three-phase motor to be used. As regards the driving of auxiliaries, and particularly of live-roller gear, in the past there were special advantages in using d.c. motors, because these could be provided with a split carcase, giving quick dismantling, and a large air-gap, giving greater safety, while a very strong design of machine was available in the standard traction motor to meet the arduous conditions of service. As opposed to this the standard a.c. motors available were not mechanically strong enough for live-roller work, were not made with a split carcase, and had only a small air-gap. About a year ago, however, the first a.c. motors specially designed for live-roller conditions were first manufactured in England, at the Witton works of the General Electric Company, and these motors embody, in addition to other features, the characteristics that formerly were the property of only d.c. motors. They have split carcases and bearings, very strong construction, a large air-gap, heat-resisting insulation, large slip-rings with heavy brush gear, and symmetrical shaft extension at each end. They are designed to give a very large starting torque, and both rotor and stator are bar wound. I think on the whole they can be considered to be more robust than the d.c. machines. In future, therefore, where alternating current is used there will be no need to go to the expense of converting to direct current for use on live-roller gear or auxiliary motors. For live-roller gear, I think in many cases the series characteristic of the d.c. motor is of no advantage. I have been closely associated with the use of the special three-phase motors referred to above and have made some fairly complete tests of live-roller gear on several mills. I give below some few extracts from these tests which may be of interest, and in the case given the heating limit is what settles the size of the motor and not the overload capacity.

| | |
|---|---|
| Number of cast-steel rollers .. | 5 |
| Weight, each .. .. .. .. | 2 tons |
| Diameter of each (length, 9 ft.) .. | 2 ft. |
| Number of plate-built rollers .. | 4 |
| Weight of each roller .. .. | 1,875 lb. |
| Diameter of each roller .. .. | 2 ft. |
| Rate of acceleration of all the rollers at circumference .. .. .. | 1·33 ft. per sec. |
| Speed of rollers at full-load speed of motor .. .. .. .. | 510 ft. per sec. |
| Weight of ingot .. .. .. | 3½ tons. |
| Normal working speed of rollers .. | 82 r.p.m. |
| Equivalent full speed of motor .. | 470 r.p.m. |
| Equivalent friction load at full speed | 26·2 h.p. |
| Power to accelerate motor .. .. | 6·2 h.p. |
| Power to accelerate rollers .. .. | 12·2 h.p. |
| Power to accelerate ingot .. .. | 5·0 h.p. |
| Extra friction due to ingot .. | 2·0 h.p. |
| Total power .. .. | 51·6 h.p. |

In the above case the motor could develop more power than was required to accelerate in the time necessary, but when run as a totally enclosed machine it was too hot and normally had to be run with the covers off, as it was not a motor specially designed for live-roll work and the insulation would have been damaged.

**Mr. A. P. Pyne** (*in reply*): It is interesting to note that Mr. Arnett has had such satisfactory experience with a.c. motors. His reason for advocating that when two motors are coupled up to one live-roller train they should each be of sufficient horse-power to operate the train, is entirely different from the object which I had in view, namely, when a standard motor of suitable size is not available two standard motors of lower horse-power could be connected to the same train to avoid the use of additional sizes of motors. Both objects are, no doubt, equally desirable. With regard to the screwing-down gear, the 50-h.p. motor I referred to in Table 4 was operating a 36-in. cogging mill, the actual horse-power taken being 21·4. The motor in this instance was rather on the large side, a spare motor having been used. I certainly consider that eddy-current control would be ideal for screwing-down gear, though my experience of this type of controller has been limited hitherto to shipyard machines, which, however, have not given rise to the troubles Mr. Pickett appears to anticipate with regard to acceleration and overheating.

Mr. Booth considers that the polyphase commutator motor might be made great use of in steel works. I have made several attempts to do so, but without much success, generally on account of the high price quoted and the reluctance of makers to tender for such machines to meet steel-works requirements.

Mr. Roberts raises an important point with regard to the periodical taking of clearances in the air-gaps of motors, and manufacturers could well give greater attention to this question.

Mr. Davidson's remarks are very interesting, and must be taken in conjunction with Mr. Wood's, as they presumably refer largely to the same motors, which appear to have given very satisfactory results, and taken in conjunction with Mr. Arnett's remarks, should enable anyone contemplating the installation of such a.c. motors to do so without any fear of their successful and reliable operation.

I had intended embodying in an appendix the additional information suggested by Mr. Mountain, but I regret that it is not at present available in a complete form, so I have been obliged to omit it. In any case it will not affect the discussion on the relative advantages of alternating and direct current. The illustrations Mr. Mountain refers to were of course intended to draw attention to the unsatisfactory positions in which such motors are usually placed. I had not intended to express any distinct preference for either type of motor, but to present their relative advantages and disadvantages as they appeared to me, and I should not hesitate to adopt a.c. motors for rolling-mill auxiliaries should the local conditions be such as to render this course convenient. This is, I think, borne out by my concluding paragraph.

I think it will be evident from Mr. Walker's remarks that the North-East Coast has done some pioneer work

in connection with d.c. and a.c. motors, and is certainly competent to express an opinion on this subject.

The data given by Mr. Wood, obtained from actual tests, should be extremely useful. I have had an opportunity of examining the motors he refers to, and can testify to their robust and heavy design. One need have no fears as to their reliability, and, as previously pointed out, in the majority of cases it is largely a question of initial expense; but special instances will always be found where the superiority of the d.c. motor will be obvious, and where equal results will be difficult or impossible to obtain with alternating current.

# NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By A. P. M. Fleming, O.B.E., Member.

(*Address delivered* 12 *November*, 1918.)

## THE HUMAN FACTOR IN INDUSTRY.

As engineers we are proud of the share our profession has had in bringing about victory—a share in which the electrical engineer in such a variety of fields has taken part. Our Institution has been well represented in every phase of activity, and while our admiration goes out to those who have served in the field, we none the less appreciate the efforts of those who have borne the stress of national duties at home.

We have reason to feel proud that the prestige of our nation and Empire will be for ever enhanced on account of the reason for which, and by the manner in which, it has conducted war. We have cause to rejoice that the anxiety and menace and war strain of the past four years are over; but in doing so I am sure we shall be mindful of the feelings of those of our fellow members on whom the price of victory has fallen heavily—those who have poignant memories to cherish.

The activities of all of us will now be directed from destructive to constructive labours, and in the electrical industry there is promise of such a future and progress that will transcend even its remarkable past.

It will be impossible to revert to our pre-war industrial attitude, and post-war industrial policy must be characterized by that boldness, freedom, and breadth of outlook to which war has accustomed us, suffering none of that paralysing handicap arising from an unduly high regard for tradition. Many of the expedients found necessary in war time will require to be continued in the even more exacting times of peace.

Considerable attention is being directed to plans for reconstruction, and careful surveys are being made of conditions likely to affect industry in the future, such as increase in production, the elimination of wasteful competition, tariffs, supply of raw materials, demobilization of military and naval forces, change in character of manufacture from war to peace conditions, women in industry, wages and many others. All are important problems, each bringing many subsidiary ones in its train. Some are of a transient character and must not be confused with those important problems which must be correctly solved if the prosperity of industry is to be built up on a lasting basis, in the light of fundamental principles.

Causes which produce changes in industry, as in other human affairs, usually precede by a considerable period the changes for which they are responsible. Only in the course of time is it possible to predict with some degree of certainty the trend of evolution in future. During the war period, however, social, economic, and industrial changes have quickened and crowded upon each other with startling rapidity. One result is a newer outlook, a new ethical attitude towards industry, portending further changes, the significance of which can at present only be dimly discerned. Amidst the perplexing variety of opinion, despite the difficulty involved, it is necessary to examine facts and to strive to understand the fundamental considerations, so that it may be possible to disentangle the essentials and without being distracted by purely secondary considerations to form an idea of the manner in which industry will develop.

In this connection, I have no hesitation in suggesting that the most important of all the problems with which we have to deal, and one which will be of increasing importance in future, concerns the human element in industry, to which I particularly desire to direct attention.

Any changes in industry that affect the human element are fundamentally physiological or psychological in character, and the mental reaction that follows physical changes may produce far-reaching and cumulative results in the minds of individuals, according to temperament, education, and experience. It is this reaction which constitutes the importance of the human element, and in the light of it and of the necessity for the most efficient production, we may examine

the more important relevant factors involved in industrial conditions. Among these the problem of fatigue deserves special consideration, not only in that it is clearly a governing factor in production, but because it has a considerable and possibly a predominating influence in forming the mental attitude adopted towards industry by workers.

Although fatigue is experienced by every human being, its causes and effects are not generally appreciated, and it may not be out of place to consider them in some detail.

### Industrial Fatigue.

Fatigue is a normal condition consequent on bodily or mental activity indicated by a diminished capacity for further exertion. The absence of customary bodily sensations of weariness does not afford reliable evidence that fatigue has not set in, as the falling off in productive capacity may, and generally does, commence prior to any consciousness of fatigue on the part of the worker. Fatigue is due to the accumulation in the blood of toxic products arising from activity in the nervous and muscular elements, and the continuance of work without appropriate rest periods results in a progressive clogging of the tissues, which ultimately causes complete stoppage of the human machine. In both manual and mental workers, it is important to note that fatigue is almost entirely nervous in its origin, and it is doubtful whether the muscles themselves ever approach a condition of real fatigue. Nervous fatigue is, of course, the more insidious form, and much more difficult to treat when it becomes chronic.

In all phases of human activity it therefore becomes essential to arrange a suitable alternation of working and rest periods, forming a natural working frequency or rhythm, in order that, during the active physiological processes which we call rest, the poison deposited in the tissues may be removed. The amplitude of the working intervals which result in the highest activity without any permanent damage to the organism—which it is, of course, unwise to exceed—will theoretically vary with the individual, but in order to meet normal industrial conditions a slight adjustment of the individual working rhythm may become necessary, in which case it becomes apparent that not only must rest periods be permitted on each individual job during the working day, but that longer intervals represented by nights and week-ends are economically necessary. This forms the argument for avoidance of overtime and Sunday work and for works holidays.

It is a matter for research to determine the working rhythms of individuals, to arrange for the rest periods required, and to convince workers in spite of their own predilections that the rest is necessary.

Many instances of increased productive capacity after a scientific adjustment of work and rest may be cited, such as one in which girls engaged on monotonous work at a bleachery were allowed three intervals per day, each 45 minutes, one being for dinner. When these times were re-arranged so that they had 80 minutes' work and 20 minutes' rest throughout the day, the output went up 60 per cent. An arrangement of spare hands prevented machines being idle. When workers were allowed to choose their rest periods they took a few long intervals, with unsatisfactory results.

The correlation existing between industrial fatigue and accidents is so marked that the occurrence of the latter is utilized as a measure of the former—provided the nature of the accident is of such a character as to involve the human element and that it does not arise through causes outside the worker's control—this forming one non-laboratory method of testing the presence of fatigue. Statistics show that the number of accidents happening increases as the working period proceeds, with a diminution prior to the dinner interval. The number falls considerably on resumption of work, increases steadily throughout the afternoon, but again diminishes, due to the anticipation of freedom, before the day is ended.

The influence of the mind on the body in industrial operations is considerable, but little understood. At first sight it might be supposed that workers engaged in purely repetition operations would soon automatize their work, relegate it to the lower or secondary nervous centres, think about other things while work is in progress, and therefore suffer little fatigue. This, however, is not the case. The influence of an emotion such as interest in or fondness for the job has a remarkable effect in staving off fatigue, and there are profound economic reasons, therefore, for effecting this interest, whether it be by sufficient remuneration or by encouraging workers to understand the job thoroughly. When industrial operations are complex and frequent, but irregular in their incidence, the worker becomes worried, as the frequency of occurrence is greater than his natural working rhythm.

The remaining non-laboratory method of ascertaining fatigue involves the measurement of output, preferably of a standard uniform product, over stated intervals, say of one hour each, during the day. This must be continued for long periods to eliminate all local variables such as the health of the worker, discontent, and incidence of holidays.

Laboratory methods of fatigue measurement have made but little progress, and in any case conclusions arrived at cannot be applied to industry without considerable qualification, partly necessary through the different circumstances in which the human element operates, and partly because one muscle or group of muscles is isolated and studied. The simplest instrument is due to Dr. Angelo Mosso, of Turin, and was called by him the "ergograph." The hand is firmly fixed, palm upwards, and a string is attached to the middle finger, the raising and lowering of which raises and lowers a weight and thereby makes a mark on a revolving drum showing the height the weight is raised. The period of raising is about two seconds. The height rapidly falls off as fatigue increases.

These methods, of course, apply to fatigue, muscular or nervous, arising from muscular processes. Methods of testing mental fatigue are simpler, and are in more frequent use. They involve tests of correctness of performance of simple mental operations over periods

of time in order that fatigue may have an opportunity to operate.

The problem of eliminating excessive fatigue and its attendant evils from industry is much simpler than the foregoing would convey, as there is no doubt that the greater part of industrial fatigue is entirely unnecessary, partly owing to the enormous amount of wasted movement and wasted time on the majority of industrial operations, and partly owing to the difficulty arising in concentrating attention due to poor working environment. The former may be largely remedied by what has been termed "motion study," the latter by that improvement in workshop conditions generally carried out under the name of "welfare work" or "betterment."

### Motion Study.

While the analysis of and elimination of waste in individual motions was implicit in the work of Taylor, the chief work of developing methods of motion study is due to Mr. Frank Gilbreth, who introduced considerable improvements in connection with his original craft of bricklaying. Considerable discussion has raged around the effect on the worker of scientific management generally, and of motion study in particular.

It may be broadly stated that the application of motion study has succeeded where its introducers have succeeded—and has failed where its introducers have failed—in taking the human factor into the fullest consideration; and in view of the generally mistrustful attitude and powerful organization of the British worker, its application in Great Britain must be even more cautious than in America. Indeed, it may be said that intensive methods should not be introduced into any works without the fullest knowledge and consent of the workers themselves, who will naturally ensure that they are in no way prejudiced and that they will, in fact, benefit by the change. To ensure success, the change must be preceded by an educational campaign, which will enable workers to give it their fullest consent and co-operation, and preferably should be developed by those in the works organization, rather than through specialists outside it, as it is a natural and inevitable development in management based on known principles and not a new remedy for industrial diseases known only to a few. It will fail, however, if the tabulated principles are applied to a new case in a purely mechanical fashion, without taking into account all the special factors involved and choosing lines of procedure accordingly.

It is often contended that motion study transforms a man into a machine; but this argument is based on a misconception. Any man working at any job gradually and unconsciously cuts down each motion involved to a minimum, and progress towards mastery inevitably results in the use of least effort. The characteristics of skill are perfect sureness and ease of execution. The use of the slide rule or shorthand in facilitating procedure is not usually considered to have bad effects, and it is difficult to persuade those who become acquainted with such labour-saving devices of this kind to revert to more laborious methods. In industrial operations, as in others, skilled and expert analysis of the job and the elimination of unnecessary motions are bound to provide, when necessary motions are synthesized, a considerable saving of time, even where they are ordinarily performed by skilled workmen, who find advantage in instruction just as would a student of the violin. To suppose that skill cannot be communicated or assisted by instruction is to place a serious limitation on industrial development; for one of the most striking developments in modern management is the application of the highest intelligence to the guidance of workers of the lowest intellect, there being no loss of directive power through the order passing from the executive through a number of grades of workers before it reaches the individual affected. In view of the tendency of small-minded workers to take advantage of petty authority, this in itself may have favourable results in establishing a better contact between management and workers.

The obvious result of motion study is to increase production, with a diminished wear and tear of the human being. A consequence of the increased production will be decreased working hours, and this increase will have to be taken into consideration in determining the period of optimum effort, the period during which the human organism can work continuously at its highest level without there being any danger of temporary or permanent damage. It is obviously undesirable to keep a worker in a factory for six hours if he can do as much work as is good for him in three. It is further necessary to settle for each industry the number of such periods and the length of the rest periods for a working day and to place due restrictions on overtime and Sunday work. There is a good deal of discussion as to what should be the length of a working day. A little consideration will make it clear that while in general a certain period might be stated beyond which the majority of workers cannot efficiently operate, a more thorough and scientific study of the problem will no doubt indicate that the most efficient working period will vary in different trades and in different kinds of employment and even at different seasons of the year.

It will be seen later that selection and training have considerable influence in securing that workers in any trade or craft shall have approximately equivalent working rhythms, so that, while the bulk of the workers are not compelled to go the pace of the slowest, there are no workers so slow that average pace would not give the production required.

Examples of the savings arising from motion study should be taken with caution and reserve, as the net saving can only be ascertained after the energy expended in placing parts in position has been taken into consideration.

A study of fatigue in industry and its relation to industrial efficiency has been the subject of much research, the results of much of which have been published in papers before the British Association, in Home Office and Ministry of Munitions Reports, and in scattered papers and book publications. The recently established Board of Industrial Fatigue is

a further evidence of the recognition of this very important industrial problem, and it is to be hoped that results of far-reaching importance to the future of industry will accrue from its labours.

### Working Environment.

The attainment of highest efficiency involves the employment of workers under conditions devised so as to facilitate concentration of attention on the work in hand. The necessity for good working conditions has been recognized for many years, and the Factory Acts crystallize the desirable minimum of welfare work of a century's experience; these changes have, however, been largely directed not so much towards securing minimum conditions for the human element in industry, as to ensure that the conditions provided by the good employer do not penalize him unduly compared with a bad one. The introduction of welfare work, as such, dates from the realization on the part of employers that under modern industrial conditions work is best performed in good surroundings by contented, healthy human beings. The welfare department should see that factory air-space, heating, lighting, ventilation, and sanitary conditions are suitable and adequate for the numbers employed, and should undertake arrangements for the provision of meals at cost price, for refreshment during working hours if and where necessary, for medical and surgical attention for workers requiring treatment. Medical examination prior to engagement will prevent the starting of obviously unsuitable applicants, and a broadly organized department may assume control of the engagement of all workers and undertake tests referred to below in connection with selection. The welfare department may form a reliable indicator of works feeling, but since it is maintained by the employer, this is more accurately gauged by the works committee. The latter does not, however, render the welfare department any less necessary, as economy results from sub-division of function, and in any case a good welfare department may be a strong conciliatory force in the works, if only in preparing the way by educational work for adjustment in the views of employers and workers.

Welfare work has been strongly criticized by the workers, particularly the women workers on behalf of whom much of it has arisen since the outbreak of war, on account of its tendency to weaken the so-called solidarity of the working classes and to render membership of trade unions a less pressing necessity. Workers, especially British workers, also regard with suspicion anything which is prompted by a spirit of benevolence or philanthropy. They do not want paternalism or charity. Much ground for dissatisfaction undoubtedly exists also in the appointment of unsuitable men and women as welfare supervisors.

The development of Joint Standing Industrial Councils and the tendency towards further organization in industry are removing the causes of these objections; and in any case we can have no sympathy with those extremists who object to any improvement in industrial conditions because they reconcile workers to wage slavery.

Care should be taken to respect the Britisher's desire for privacy, and no out-of-works hours activities should be undertaken without expressed desire and permission. The ideal course is to offer every encouragement to workers, especially juvenile workers, to co-operate in leisure activities, in which all may share if they choose, thereby developing a valuable esprit de corps which is the germ of the spirit of industrial patriotism.

Extravagance must be carefully guarded against in welfare. Because improvement in conditions enhances production, it must not be supposed that this is true indefinitely. A point may be reached beyond which conditions are so comfortable as actually to militate against efficiency.

### Selection and Training.

The provision suggested with regard to fatigue and welfare presupposes the employment of individuals normally fitted for the performance of ordinary industrial processes; that some policy of selecting workers is pursued, and that selection is followed by appropriate training; for the arrangement of suitable industrial environment is a mere refinement to this more fundamental requirement.

It is not necessary to labour or to illustrate the thesis that an enormous increase in industrial efficiency can be obtained by placing the "round peg in the round hole," and that the higher the degree of specialization in industry the more desirable does it become that each man's potential capabilities should have some relation to the character of the employment. The highest degree of industrial efficiency and satisfaction with the work follows if the worker's inherent capacity, as developed by education and experience, is utilized.

Education obviously will play a great part in enabling the individual to find out in which direction his most fruitful field of activity will lie, and we should arrange our educational system so that it develops orderly and logical methods of thinking, capacity for observation, and accuracy in thought and speech, and that it does not stereotype the mind and repress originality. This development will not be confined merely to school hours, and opportunities should be sought of encouraging innate tendencies to show themselves through hobbies, visits to works and public institutions, etc. A most important feature of educational life is the inculcation of esprit de corps through games and other collective activities, as team work is the most pronounced characteristic of modern industry. Education, therefore, should endeavour to render articulate all those tendencies which will enable selection to be made, and to assist the youth to realize himself.

In the past, selection for industrial occupations has been of a haphazard character. In the case of youths entering the engineering trades it has been frequently left to the unstable judgment or caprice of a foreman without qualification for such a vital matter. In other cases, academic qualifications have been a determining factor in spite of their acknowledged uncertainty as guides to industrial success. The least

usual and, under present conditions, most satisfactory method, although costly in time, is that of practical trial.

It must not be hastily assumed that selection is a purely mechanical process which can be put into operation like a sieve to sort men out, for the situation is much more complicated.

Some of the most interesting developments in connection with selection have been psychological in character. The problem can be approached in two ways. The individual can be examined psychologically, with a view to discovering his natural capacity, and the employment demanding such capacity can be determined. Conversely, when workers have been required for specific purposes, the basic characteristics of the work have been determined and a psychological examination made of a group of candidates available to discover the most suitable candidate.

It is unlikely that psychological methods will be employed for some years to come, as psychologists have not yet formulated general lines of procedure with sufficient accuracy, and it would be grossly unfair to psychology to expect too much, because of the danger of inevitable reaction. Moreover, in addition to the sensory characteristics tested for specific purposes, each job may require mental and moral qualities such as perseverance, tact, honesty, etc., and the examination results would have to be weighted with these considerations before final decision.

This need not discourage us, however, from progressing along other lines. We know that for technical positions, educational qualifications have necessarily been an important guide. Subsequent progress depends largely on the individual desire to succeed, due to the incentive of increased responsibility and remuneration, and, in general, merit has to a considerable extent met with its reward. The process has been akin to the natural process of survival of the fittest, and may be termed "self-selection," since the individual largely determines his trend up or down.

Since this has led to results which are good within certain limitations, we may legitimately seek to extend the principle where possible by giving the individual every opportunity of developing his capacity through education and training. This step may be termed "self-realization." In the training of the young engineer the period of works training is from this point of view merely an extension of the college course. Subsequently, after being trained the individual may be given the fullest opportunities of performing to the limit of his capacity that work for which his ability and experience fit him. This step may be termed "self-expression"; and with perfect self-realization and perfect self-expression, the principle of self-selection would be carried to such an extent that probably extraneous methods of selection would be unnecessary. In order to achieve self-selection more fully, not only must the general proposals regarding education be carried into effect, but nepotism in industry, a fruitful cause of discontent to workers and lack of ambition in technical staffs must be eliminated.

There is no reason why this principle of self-selection should not be applied to workers in the shops. Among manual workers there is much less ambition than among technical workers, and the necessary stimulus can be given by providing a channel of upward mobility and an incentive in the form of higher earnings. The obstacle to progress which meets the manual worker, and the tendency of the minimum flat rate of trade-unions wages to become a maximum —due partly to employers and partly to the workers' ideas regarding restriction of output—are the prime causes of this lack of incentive.

Reverting to more specific methods of selection reference might be made to the choosing of men for war services. Major Yerkes, acting as President of the American Psychological Association, has devoted himself to the special problem of devising ways and means whereby the American psychologists might assist the American War Department. He organized 12 committees of psychologists, and each committee inquired into and reported upon the special characteristics required of men working in the main branches of the services, and also consulted other authorities in order to discover the best means of co-ordination between existing organizations. Arrangements were then made for a definite plan for the psychological examination of recruits. The procedure was substantially that of a psychological and medical examination, as a result of which all recruits were graded into three main divisions, viz. inferior, normal, and superior mental types. The normal group, probably about 80 or 90 per cent of the total, was passed without further examination as mentally competent, but the other two groups were given special examination with a view either to rejection or to employment in special capacities. This initial groundwork led to the selection of men for special branches of the U.S. Army, and branches of service requiring special capacity are now being recruited from those who have revealed that capacity during these examinations.

In connection with aviation, the essential characteristics of successful and unsuccessful aviators have been examined by medical men and psychologists, and both in this country and in France methods have been devised for effective selection of men possessing the necessary psychological and physiological characteristics. As a result, it has been possible to set forth the characteristics required by successful aviators, and it is said that the devices at present employed afford a very speedy means of choosing those who are likely to succeed from those who do not possess the special qualifications required for this branch of the service. Much apparatus has been devised with recording mechanism whereby characteristics can be automatically indicated according to their expression through individual actions.

In connection with gunnery, signalling, and other special requirements, similar measures have been taken, and the results go to show that, provided the characteristics of employment, whatever the grade of work may be, can be sufficiently well defined, methods may be devised whereby the probability of a candidate being psychologically and physiologically fitted for work can be more or less readily determined. That is to say, instead of employing men on the off-chance

and rejecting them if after a period of working they are not satisfactory—a very lengthy and expensive operation—it becomes possible to select fairly rapidly from a large number those who possess the inherent qualifications, and the process of trial and error can then be put into operation on a limited number with considerably greater chances of success.

The idea of training is a necessary complement to that of selection, for training renders the selected worker fully productive and efficient in a minimum of time. It is futile to endeavour to train workers engaged promiscuously; it is wasteful to leave carefully chosen workers to pick up their occupations for themselves.

In general, suggestions for training have been confined to young people entering the skilled trades, who require a long period of the nature of apprenticeship. The necessity for instructing dilutees and women workers and the arrangements required for fitting discharged soldiers for industrial life have made it abundantly clear that for the majority of occupations the period of training, provided it is sufficiently intensive, can be cut down to a relatively short period. For the electrical industries, however, many of the operations remain of a skilled character and require a period of several years during which the learner may acquire practical experience; and, in addition, owing to the wide variety of materials used and the desirability of understanding the principles of the processes and operations employed, it is necessary to have this accompanied by some form of instruction. Further, the probability of far-reaching changes arising from industrial research and advance suggests that the future workman must have his general intelligence developed so that he can appreciate the importance of these changes and adapt himself without difficulty to new conditions. He must have considerable mental resilience.

Those youths who will in all probability compose the rank and file of industry, will enter works before the age of 16, and will be required under the new Education Act to have continued education until the age of 18. It is most essential that this, as well as their pre-works education, should embrace a knowledge of the principles of industrial economics and of industrial history; and, further, they should be taught the elementary principles of science underlying the trade in which they are engaged. Steps should be taken to instil a knowledge of the elements of physiology and hygiene and, by the fostering of outdoor games, to develop the latent desires for wholesome environment, mental and physical. While the value of this cannot be fully realized unless it is accompanied by better housing and home conditions, happily these are now securing attention. It is from such training that one may look for demands from workers for better conditions in the factory. It is infinitely preferable that such conditions should be brought about through the desire of the workmen rather than that they should be pressed upon them by the employer.

During the continuation education period it is to be hoped that attention will be given to subjects of an economic character, and to the debating of these subjects so that workers may be articulate and be able to appraise at their proper value the arguments, often quite unsound, of would-be reformers. It is sometimes urged that the period of continuation education should be devoted essentially to general education. This would appear to be a grave mistake, in view of the importance that all industrial matters will have to the youth throughout the rest of his life. We have now got beyond the point of considering industry a necessary evil.

While it is not necessary to enter into discussion of the channels through which continuation education can best be applied, in an industrial sense the greatest importance may be attached to works schools, not only in that they offer the best facilities for the efficient training of boys engaged in industry, but because through them it is possible to foster good relations between the future workman and employer by contact between themselves and the staff during the educational period. Further, such schools offer opportunities for developing powers of self-government and for the inculcation of the qualities of citizenship.

The teaching of the principles of industrial economics, and their application in the everyday life of the youth, would do much to clear away the misconception that the economic interests of the employer and employee are necessarily opposed. Further, the reasons for and means of achieving elimination of waste, whether of time, effort, or material, can be taught with better effect to the youth rather than to the adult whose habits are already well fixed.

During this educational period it is incumbent upon the employer to establish the principle of providing means for the upward mobility of each youth irrespective of social distinction. Channels can be arranged through the various grades of work, positions and facilities provided, either by scholarships or works educational arrangements, whereby youths can acquire the education and knowledge requisite for any position, provided they have the ability and powers of application.

Regarding the higher staff positions embracing technical, scientific research, commercial and management positions, little need be said about purely technical education.

The facilities for training in research are at present too few, but there are many indications of developments that will remedy the present defects. The universities are attempting to afford suitable training, but there is required in addition training in large industrial laboratories, such for instance as that afforded by the Mellon Institute of Industrial Research, or the National Physical Laboratory. This gap will be filled possibly when more of the large industrial concerns establish their own research organizations.

With regard to commercial training, it is interesting to note the developments that are taking place in certain of the universities in providing business courses, and the fact that these are conducted in the university atmosphere and alongside studies relating to science and art, will do much to ensure the students who take such a course acquiring this education in its broadest form.

The most urgent changes are required in connection with the training of works managers. Modern conditions are such that special training is required, as modern management has a technique quite apart from the technology of the particular works managed, and this produces similarities of temperament and training among managers in different industries which transcend differences due to trade materials and processes. Managers require to be broad-minded men, capable of handling tactfully large numbers of workers, of appreciating their points of view, and of deciding justly between conflicting claims. Questions like industrial organization and administration, fatigue, welfare, selection and training, and trade unionism, must be their special study. In Manchester, a Directorship in Industrial Administration has been established jointly by a few leading firms and the university authorities, for the purpose of providing a satisfactory course of training for present and future managers.

### Co-operation in Industry.

Having considered those conditions relating to the human element that are of fundamental importance to industrial workers as individuals irrespective of the positions they occupy, attention may now be directed to those factors which influence relations between groups of workers in industry, represented on the one hand by the rank and file, and on the other by the management. All benefits arising from the improvement of individual efficiency will be lost to industry without successful co-operation between these two groups. In the past this co-operation has often been entirely lacking, and is always far from complete. Prior to the war, the prevailing atmosphere among the various grades of workers in British industry was one of suspicion and mistrust, and although workers in this country possess the greatest manipulative skill, and in a superlative degree innate common sense and intelligence, and while British executives are most capable organizers, the result of their co-operation has been far from what one might expect if all these favourable factors had been working in complete harmony. This condition indeed gave rise to serious cause for alarm. The causes of this lie deep in the rise of the factory system itself, and can best be appreciated by considering the stages through which industry has evolved.

The beginnings of industrial organization in this country are to be found in the Craft Gilds, which developed subsequent to the time when English economic organization was chiefly agricultural. The Craft Gild included as members all those who plied a given trade and provided facilities whereby both the economic and social needs of its members were satisfied. In the economic aspect the Gilds were required to insist on a standard of workmanship, to ensure equitable bargaining conditions between craftsmen and the general body of consumers, and to eliminate anything from trade organization that would tend to operate to the disadvantage or even inconvenience of the consuming public. In this sense it is interesting to observe that restrictions affecting night work were imposed with a view to preventing bad workmanship and inefficient inspection occurring in artificial light, and thus preventing the supply of inferior goods to the public.

In the mediæval period industry was therefore naturally a part, and a subordinate part, of healthy happy human life. It was subservient to the well-being of the Gild members. Between them there existed a sense of duty, a spirit of comradeship and social discipline, which found its expression in definite social activities as distinct from the industrial activities of the workshop or the home.

The Gild system, which flourished during the fourteenth and fifteenth centuries, gradually decayed and was superseded by another type of industrial organization. The place of manufacture, which naturally enough was originally the region in which the necessary raw materials were found, became removed from the sources of raw material, as the consumption increased and local supplies became scarcer. A new type of worker, the entrepreneur or middleman, arose, whose function it was to collect raw materials for domestic workers and to deliver to various markets the products of manufacturers. During the seventeenth and eighteenth centuries the middleman became the owner of the capital necessary to purchase raw material and took all risks incidental to manufacture. The loss of control by the workers over working conditions had commenced.

The discovery of iron and steel, the textile inventions, and the steam engine ushered in a new and still more remarkable industrial epoch, the chief characteristics of which have been the development of the factory system, specialization and sub-division of labour, and standardization. Workers went to factories for employment, and no longer owned the instruments of production.

It is sometimes suggested in view of these comparisons that we should do well to revert to the mediæval Gild system, but we have entered on a mechanical age in our civilization and we cannot go back; the path of progress lies forward. The life of the mediæval worker while different in many respects from that of the modern worker, was relatively limited and clannish.

Through machinery we have made remarkable achievements, and life to-day is an infinitely broader thing than it was. Not the least of its results is a tremendous increase in population, which would alone preclude any abandonment of intensive methods of production. Our task is to remodel our industrial system so that the neglected human factor is properly considered, to preserve the advantages of machine production, and to bring back the good features which the mediæval system possessed. In the Gilds, the ever-present human element was recognized and not denied. Its claims were appreciated and due provision made for their satisfaction, with the result that industry satisfied national demands by providing goods of high quality and secured the operators a standard of life, a degree of independence, and a source of happiness. The changes brought about by the industrial revolution have been so startling and rapid that there has perhaps been some reason for the lack of consideration of the human factor, for it was impossible to foresee whither industry would tend.

The rise of the industrial system shows clearly, however, that whenever the human factor has been ignored or opposed, consciously or unconsciously, dissatisfaction, strife, and frequently open rebellion have been the inevitable consequences. It is not merely necessary to remedy exising evils, the day-to-day development must be closely watched so that the seeds of further trouble are not sown.

There is scarcely any evil present in modern industry which cannot be removed by considering its effect on the worker without in any way sacrificing the valuable features of the present system. Considering the conditions that make the absence of industrial co-operation, one dominant feature stands out, namely, the absence of a strong national permeating influence of what might be termed "industrial patriotism," replacing the mutual mistrust between employers and employees. While the latter is usually indicated, or at any rate accompanied, by controversies relating to wage matters, there are many other concomitant factors which require consideration, and wherever there exist workers living under conditions that are unhealthy, drab and squalid; workers possessing insufficient means to maintain healthy physique and a standard of living requisite for modern conditions of civilization; inequalities in opportunity for social and economic advancement by merit; a lack of security of employment; entire absence of control of working conditions; lack of opportunities for the development of latent desires for culture; insufficient knowledge of the fundamental principles of economics; insufficient education to enable judgment at their proper value of the half-truths of agitators, whose enthusiasm is generally inversely proportional to their knowledge of economics; managers who do not appreciate the hopes and aims of workers, considering them only as productive units—just so long will the interconnection between the two groups tend to perpetuate the mistrust born of generations of past industrial oppression. Wherever these things and the causes of these things exist, we cannot hope for industrial workers to be able to exercise that balanced judgment necessary to their complete co-operation.

There are happily many indications that the community at large is giving earnest attention to these problems, as is indicated by many efforts which are being made towards tentative solutions. Bodies such as the Industrial League and the National Alliance of Employers and Employed will enable workers and employers to meet on equal terms. The medium between the management and workers now developing so rapidly is the Works Committee, a popularly elected body having one representative from each department or trade in the works, and electing its own chairman and secretary. This body should form the natural channel for grievances, complaints, and suggestions emanating from workers, which can be discussed by the Committee and submitted in an impersonal way to the management.

For reconstructing industries as a whole, the Whitley Report suggests the formation of Joint Standing Industrial Councils. Such Councils will undertake to consider problems for each industry relating to post-war conditions, demobilization, apprenticeship, rationing of raw materials, etc., and would also endeavour to include in their scope more permanent questions relating to the trade such as research and education, export markets, the relations between labour and capital. The members of Industrial Councils will not act in an individual capacity but will be representatives of manufacturers' associations and of organized bodies of workers in the industry. The most valuable feature of the Council will be its power to settle many questions entirely without Government interference. In these ways the legitimate desire of the worker to see and to know more about the inner working of industry with which he is connected may to a considerable extent be gratified.

In brief, the introduction of any modification into the industrial system postulates the co-operation of all grades of workers without reservation or qualification of any kind, and before this can be accomplished a long and painful educative process has to be pursued. The worker virtually has it in his or her power to render null and void any improvements which are not preceded by this fundamental orientation of view.

The problem of reaching the highest attainable degree of industrial efficiency is therefore one of developing in workers the right feeling; and the criterion of success in all effort towards it should consist in the extent to which it promotes a correct attitude of mind and a spirit of trust and confidence between workers.

### Lines of Advance.

The rapid changes in social and economic conditions during the last few years indicate that we are on the threshold of a new industrial epoch, bringing with it new possibilities for retrieving the errors which have militated against industrial development in the past. The probable lines of advance, bearing in mind the fundamental principles underlying the human needs of industry, may be briefly outlined.

A primary necessity for each worker is good health, conserved on the one hand by a knowledge of physiological and hygienic laws, and on the other by suitable environment. Medical services should be preventive rather than curative. It is too often forgotten that the nation's human assets are its real wealth.

Domestic conditions form one of the most considerable influences affecting workers, and more than any other single factor will, if good and wholesome, tend towards formation of character and the inculcation of self-respect. The establishment of good housing conditions forms an important feature in stimulating this influence.

The education of the young people should aim primarily at the development of character, and in this respect should reinforce good home life.

The most valuable faculty required in industrial life, which can be developed to some extent by education, is the capacity for team-work. It may be termed "disciplined individuality," and while it recognizes the right of the individual to fullest development, it seeks to subordinate it where so developed to the need of the community. The existence in a works of young people with common aims and interests provides unique opportunities through games and other activities for

the development of a corporate spirit and for self-government.

The remaining function of education is to develop the capacity to make use of opportunities, that will-power without which the existence of machinery provided by attempts to solve our industrial problems will be useless. Education can inculcate the discipline to achieve, and through it future workers can be taught to demand and to expect that working environment which promotes conservation of effort and attention and freedom from strain.

The fuller realization by employers of their responsibilities towards education will result in the further establishment of works schools as means of providing continuation education, and the principles of proper selection and training of each grade of worker according to function will become recognized. As part of the continuation education, the teaching of the principles of economics and their application to industry will enable workmen to appraise the views which are current regarding the future of industry, and particularly will enable them to abandon with clear consciences the idea of the limited amount of work to be done and its paralysing consequences in restriction of output.

Those who argue in favour of democratic control seldom remember that exercise of control involves responsibility, which in turn demands wide experience and knowledge. A plan which would remove a great deal of doubt and mistrust from the minds of workers would be a recognition of the principle of upward mobility, by which all those engaged in industry having special capacity or latent ability may rise to positions in which it may be utilized. This policy involves promotion of men from within each works organization, in connection with which works schools offer unparalleled opportunities of selection. Young men of special promise may conceivably be sent at the firm's expense to a university for a full technical course. Apart from the value of this step to the men concerned, it would have a profound influence in stimulating other workers. The opening of higher posts in industry in this way to the rank and file would increase confidence and diminish the demand for democratic control, which is so largely a protest against nepotism and against arbitrary selection of men together with the association of any special grade of worker with a particular social standing.

It is essential that works managers of the future be broad-minded men of understanding and sympathy, and able to appreciate points of view other than their own, and to give due attention to the human element in industrial organization. They should be able to counteract difficulties which arise merely through the separation of workers from management and which are incidental to the employment of large masses of workers. As an indication of the new attitude of mind it is of interest to note that the manager of a large industrial concern has offered apprentices in the firm's employ a large shield, which is awarded each year by the apprentices themselves to one of their number, who is distinguished not by excellence in workmanship or in examinations but by public spirit and service.

Managers may be assisted and guided in discharging these functions by one or more specially chosen staff officers, whose business it will be to study everything pertaining to the human element, particularly the relations between management and workers. The business of a factory is to make men as well as machines.

In connection with social, economic, and industrial changes, considerable experiment is required in order to determine which changes are desirable and which are undesirable. No limitation or restriction should be placed in the way of the varied forms of organization existing in education, industry, and social life. Experiments such as the Little Commonwealth should be carefully watched for application to future developments.

The keynote of all the changes proposed lies in education, general and technical, and this is of such importance that the course which is the best preparation for a youth's ultimate future must not be prostituted for immediate industrial requirements. Every means must be taken to develop all his inherent faculties to their maximum capacity, and it is the responsibility of the industrialist to see that these faculties are most wisely, effectively and fully used for the benefit of the whole community.

Older workers may have facilities provided for obtaining a broader culture than they have yet known through greater leisure and the opportunities provided by local education authorities and the Workers' Educational Association. It is particularly important that economic teaching should not be of the character of partisan propaganda.

Above all, it is the human needs of the individual worker which must be studied, rather than consideration of workers in the mass, and the individual worker must be encouraged to be articulate and to realize and to let others realize these needs so that they may be satisfied. The loss to industry during the last four years of personnel, constructive production, and retardation of normal development, combine to render necessary the utmost attention to the human factor in order to minimize the inevitable devitalization.

## Conclusion.

We have considered the various means which make for improvement in the material prosperity of those engaged in industry. It is useless, however, to provide the means unless the will is also present to employ them. In war time the morale of the fighting forces is maintained partly through patriotic sentiment, partly through fear of the consequences of defeat, and partly through pride of achievement. Without these incentives failure would result, no matter how perfect the weapons and machinery for conducting war. Some counterpart of these qualities is required for peace time, a carrying-over of the moral stimulus of war to peace, an industrial patriotism, that something which Maeterlinck calls the "spirit of the hive" in industry; pride in quality of workmanship; appreciation of the fact that industry in its highest form is nothing more than a national service which converts some natural product into a form more suitable for the requirements of the community, a service towards which those feelings

of patriotism and mutual self-sacrifice which have been distinguishing features of the nation at war require to be developed. We have seen what steps must be taken in industrial reconstruction and in education to create such a spirit, and for their realization our united and untiring efforts are required. The development of this new spirit is a matter which goes further back than the schools, it enters home life and becomes a direct responsibility of parents, who themselves must, from experience and knowledge, not merely pay it lip service but share it.

In the past, material prosperity has been considered as an aim and an end in itself. The material and ethical aspects of industry are as interdependent as a sound mind and a healthy body. The material side cannot be neglected, but if developed without reference to the ethical side, industrial activities become devoid of purpose and meaning and humanly intolerable.

Consideration of the ethical aspect of industry involves the development of a new industrial ideal which would include everything that makes for the more durable satisfactions in life; it will command that loyalty, that regard for the common good which we call citizenship, the concrete expression of man's duty to the State. It would promote the cultivation of a love of art and science, and all the media of a broad and liberal culture and for the growth of a sane and balanced mental outlook. When the chief personal demands of the individual are satisfied, self-interest, the dominating factor in industry to-day, will give way to this ideal of service, which can then be stimulated, developed, and maintained.

The large part which industry plays in normal life, the manner in which it is being humanized so that it fits into life without incongruity, the development of methods of government in industry by the industry, all point to the conclusion that the future of social reconstruction lies in industry rather than in politics, although the influence of these changes may be expected to bring about profound reactions in our methods of political government.

At the present time, the most pressing problem in industrial reconstruction is the production of harmonious working, co-operation without reserve or stint, and this is a problem involving the removal from industry of all those things which adversely influence the human element. It is possible to procure a mechanical resemblance to progress by the imposition of some panacea or some machinery of reform on the community as a whole, but this will be fruitless without the changed attitude of mind, due to an influence operating through the channels afforded by each home, each school, each works. To create the confidence and trust from which this influence springs, those who control industry must bring to the consideration of the problem sincerity and good intentions, followed by wise and statesman-like actions.

While the war has shown to what extent even the most remote and aloof members of the community are dependent on ordinary industrial processes, there is still a feeling that industrial problems primarily concern only those directly associated with industry. This is far from being the case. Industry in its broadest aspect includes not only processes of manufacture but the provision of services such as transport and power supply, and the principles outlined apply in general to the whole of these activities. As consumers, if not in any other way, all are affected by industry, all are concerned with its prosperity, all have some responsibility for its proper conduct.

Now that an early and satisfactory termination of the war is assured, we are faced with the necessity of reorganizing our social and industrial life by giving effect to the hitherto somewhat nebulous proposals for reconstruction. In so doing, it will be unwise, indeed it will be impossible, to avoid making use of the experience and knowledge and of the changed attitude of mind resulting from the upheaval of the last four years. All members of the community have been subject to the same menace, have shared common hopes and fears, have been stirred by common sentiments, suffered similar bereavements, and the time has never been so appropriate for embarking on a new enterprise in which success is so dependent on united purpose and on mutual co-operation. The principles which have been outlined—summed up in a phrase—suggest that in the industrial sphere that which is ethically right is economically desirable, and if we can seize the opportunity that is now presented to secure the application of these principles, a measure of life and well-being will be assured to the community which it has never previously known.

# SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By J. F. Nielson, Member.

(*Abstract of Address delivered 12 November, 1918.*)

In accepting the chairmanship it appeared to me that members of this Territorial Centre wished to recognize the great contribution towards the successful termination of the war which has been made by that branch of electrical engineering to which I have devoted the greater part of my professional career. I refer, of course, to the application of electrical science to the equipment of ships and shipbuilding yards.

To those well-known words in the "Articles of War," "It is upon the Navy that, under the good providence of God, the wealth, prosperity and peace of these islands and of the Empire do mainly depend," we might not inappropriately add that "It is upon the multifarious applications of electrical science that the Navy does mainly depend for its existence to-day."

Electricity plays a vital part in the lighting, heating, ventilation, internal and external means of communication, operation, and control of every possible means of defence and offence of a modern battleship, cruiser, and even torpedo-boat destroyer. The switchboard is the heart of a battleship, the electric cables radiating or controlled therefrom are its nervous system, and any serious interruption in the electric supply affects its usefulness and may possibly endanger its existence.

This war has been unlike all previous wars in that it required for its successful prosecution the mobilization of the entire resources, scientific and commercial, of this country. Of course this is not only natural; it is inevitable in this age in which we live. In times of peace, engineering had so permeated the whole structure of modern society that without the work of the scientist, and through him the engineer, its very foundations would have crumbled away. Without the labours of the engineer we may well ask ourselves where would our means of transport by land and sea, our means of communication through the air and under the waves, our factories, mines, and every other source of wealth and comfort be to-day. So in like manner our whole output of the materials of war, our means of transport of men and of munitions, our resources for the treatment and preservation in life of our wounded, these and almost every other means by which modern warfare is carried on to a successful issue, are absolutely dependent upon the continuous and unremitting toil of hand and brain of the trained engineer.

The tragedy of this war lay in the fact that those who "willed this war" and have brought untold suffering and loss upon the world, prostituted their knowledge of science to ignoble ends. They degraded instead of elevated; they abused instead of used to noble ends the wonderful discoveries in science and engineering which we have witnessed during the last 50 years. Applying to the present situation the words used by Edmund Burke in describing the revolutionary French Government of 1796, our enemies "set this world of reason and order and peace and virtue against their antagonist world of madness, discord, vice, confusion and unavailing sorrow"; and whereas he says that the State "is a partnership in all science, in all art, in every virtue and in all perfection," we have witness of the kind of partnership in science which Germany cultivated in such atrocities as inoculation of non-combatants with deadly disease germs, poisoning and pollution of wells and springs, and wholesale incendiarism of open towns and villages.

The experiences of the past four years have taught us what nothing else could have done, that a world whose entire aims are materialistic must sooner or later fall to pieces. The future peace of the world lies in the recognition by all nations of the rights of mankind, in the due observance of the claims of humanity, and in the striving after a true idealism of statecraft as Burke has described it, viz. "a partnership in all science, in all art, in every virtue, and in all perfection."

In assisting in the creation and fostering of such an ideal atmosphere for human society, grounded upon such a partnership in science and engineering, it is surely not too much to think that this Institution should find some of its most useful work in the future.

In his Inaugural Address at the opening of last session,* the President sketched out an extraordinarily full programme of directions in which the Institution might be developed. Such a programme could not under the most favourable circumstances be completely carried out in the course of a single year. Several of the schemes which he then proposed have been successfully inaugurated, and we may surely join with him in the hope that during his second year in office we may see this programme brought to a satisfactory fruition.

Whatever may have been the Institution's shortcomings in the past, it cannot be said now that it is not taking an active interest in all that pertains to the profession of the electrical engineer and in the work under his control and influence.

I turn now to a consideration of the growth in the application of electric power to shipyards during the last 30 years.

Thirty years ago electricity was generated almost if not entirely for lighting of workshops, wharfs and ships under construction, and even then only on a small scale. Gas, naphtha lamps, and candles were more in evidence then than incandescent electric lamps. To-day the position is entirely different. The demand for power is in the neighbourhood of 85 per cent of the total consumption of electrical energy for all purposes, and this proportion continues to increase, while the lighting load diminishes relatively with the introduction of improved and more efficient sources of illumination.

In a shipyard with which I am acquainted the total

* *Journal I.E.E.*, 1918, vol. 56, p. 1.

capacity of the generators installed in 1888 was under 80 kilowatts; to-day the available generating and transforming plant has increased to over 7,300 kilowatts. Twenty-five years ago the total number of motors installed was 15, with an aggregate horse-power amounting to 40; to-day there are over 600 motors aggregating not far short of 15,000 brake horse-power. The largest motor which this particular shipyard then possessed was one of 8 b.h.p.; to-day, motors of 600 b.h.p. will soon be in operation. Last year over 13 million units of electrical energy were consumed for all purposes.

Steam was in those early days very largely employed in the generation of mechanical power for driving shop machinery and tools. The efficiency of conversion was naturally very low, as the boilers were separated from the engines by long distances and the engines themselves were both small in size and numerous, all conditions making for wasteful operation. To-day the steam engine has almost entirely disappeared and its place been taken by the rotary converter and electric motor.

It is perhaps in the matter of lifting machinery that the greatest improvements both in increased facilities for operation and in the speeding up of the transport of material have taken place during the period under review. The slow and cumbersome sheer-legs, the overhead travelling crane operated by heavy, slowly revolving shafting, and the steam-driven winch have all disappeared and been replaced by the electric cantilever and derricking types of crane, the fast-running overhead traveller, and the electric winch.

The problems to be met and overcome in equipping a shipyard, while in some respects similar to those met with in steel works, are in others quite different. In a shipyard, motors are required for operating cranes, pumps, air compressors, large machine tools, plate bending, rolling, punching, shearing and other similar machinery, but with few exceptions the motors required are much smaller and the services to which they are applied much less severe than is the case in a steel works where 10,000-h.p. motors are not unknown. At the present time the largest motors in most shipyards will probably be found to be coupled to air compressors.

The uses to which compressed air are being put to at the present time in our shipyards, and the rate at which the demand is increasing, must be giving municipal and other supply authorities cause for serious consideration, as it has come to my knowledge that during the last few months orders have been placed in this country for not less than 95,000 horse-power in motors for driving air compressors alone.

*Electric welding.*—The application of electric welding to ship construction and repair is being widely discussed in shipbuilding circles at the present time. Of course, as has been the case and always will continue to be so, one finds enthusiasts, whose zeal outruns their knowledge, prophesying the almost immediate advent of the shipbuilder's millennium—the dawn of the day of rivetless ships.

Progress in the application of electric welding to the jointing of steel structural work has undoubtedly been rapid since the outbreak of the war, but while there are now in service some small barges in which riveted joints are entirely or almost entirely absent, it seems very improbable that the present methods of riveting and caulking will be immediately superseded by any other method.

It must not be forgotten that the present designs of riveted steel structures carry the conviction of long experiment in service. Such experimental work has stood the test of the most severe conditions of sea service over long periods of years, and enthusiastic advocates of electric welding ought to realize that fact and be content with the progress that is being made in applying it at present as an adjunct to the work of the riveter, allowing such a period of time to elapse as may be sufficient to demonstrate whether the electric weld is capable of withstanding, equally with the riveted joint, all the stresses to which those portions of a ship's structure upon which its safety and the lives of those on board depend are subject. At the present moment expert opinion, strengthened by such practical experience as it has been possible to obtain, are apparently against putting the new on an equal footing with the old method. The advocates of electric welding as a complete substitute for riveting appear to base their arguments more or less upon the results of tests related to ultimate strength.

The Committee of Lloyd's Register of Shipping have recently carried out a series of tests on electrically welded joints of such form as are applicable to the structure of ships, and the results of their tests, which have recently been made public, are extraordinarily interesting and should be read by all interested in this matter. These tests were made concurrently on solid metal, riveted joints, and electrically welded samples, so as to obtain comparative results, and the stresses applied to all these samples were of such a nature as to reproduce, as closely as possible, the strains due to the wear and tear of sea service extending over a long period of years.

The results of these trials have been so far satisfactory as to satisfy this expert Committee that under certain restrictions electric welding may be applied to ships constructed under their supervision. These restrictions are briefly:—

(*a*) The constructional arrangements, the system of welding, the quality of the electrodes, and various other details in connection with the operation of welding must meet with their approval.

(*b*) The operators engaged on this work must be specially trained men, experienced and efficient in the use of the system employed, and they must have efficient supervisors of proved ability set over them.

The last restriction seems to me to be most important. Electric and any other means of welding are alike in this respect that the quality of the work done is not apparent to the eye and time alone will tell whether the job was well and efficiently done. An imperfectly executed weld in the structure of a ship's hull may spell disaster to the life of the passengers and crew.

Electric arc welding as an adjunct to the riveting of water- and oil-tight work appears to have great possibilities. Very close spacing of rivets is required to make a satisfactory watertight and, more particularly, oil-tight joint. Great economies can be effected in the amount of riveting required for this class of work if electric welding is used to close the seams and otherwise displace hand or machine caulking. The welded joint would seem to have

the further advantage over the riveted and caulked joint in that it will remain water- and oil-tight up to its breaking point. For this reason alone electric welding holds out possibilities of entirely, or at least largely, replacing caulking both in shipyards and in boiler shops. It has a wide field of useful application in workshops in building up oil and water tanks—it is not well suited for thin sheet iron work such as ventilating pipes and trunks in welding pipe flanges, filling in new teeth in gear wheels, reinforcing worn-down keys and bearings in shafts, and all such repair work in steel and iron. Indeed its most useful field of application at the present time appears to be in effecting repairs.

Considerable difference of opinion exists as to its satisfactory application to the welding of cast iron. It is, however, interesting to know that electric welding was successfully employed in repairing the cast-iron cylinders and other broken castings of the main engines of fifteen of the interned German liners in New York harbour which their crews had endeavoured to render useless to the Allies. There, again, great diversity of opinion existed and much opposition had to be overcome before sanction was given to the electric method being adopted. In a case such as this the saving of time was enormous, and in fact the work was done without delaying the putting of these vessels into commission beyond the time necessarily spent in fitting them out as transports.

From the point of view of the practical shipbuilder, welding by the electric arc process on board ships under construction presents a problem which does not appear to have been sufficiently realized by those who advocate its universal application. I refer to the difficulty of screening off from accidental view the hundreds of other workmen engaged on other work on board ship. To view the arc inadvertently at close quarters has a most painful and injurious effect upon the eyes, and in a confined and crowded space the risk run of eye injury by such men would be practically unavoidable.

Electrical engineers are naturally more interested in the supply of power and the necessary transforming plant required for this work than in the actual details of welding. In this connection there is room for careful and independent investigation to determine the most suitable system and pressure of supply for electric welding. Considerable diversity of opinion exists at present on this subject, more particularly with regard to the pressure necessary to maintain the arc and to overcome the resistance of the insulating flux covering the electrodes. When we find one manufacturer contending that while 30 to 40 volts are taken up in the arc, 90 to 110 volts must be supplied to enable this arc to be properly maintained, and on the other hand another manufacturer equally emphatic that this extra pressure represents so much needlessly wasted energy, there is considerable scope for independent research which might very well be undertaken by the Electrical Research Committee

The most interesting topic in connection with the electrical equipment of ships at the present time is undoubtedly that of propulsion. As has so frequently been the case in many other departments of scientific progress, electric propulsion of ships owes its inception to the labours of British engineers, and to none more so than of the late Mr. Henry A. Mavor. It is a matter of common knowledge that the electrically-propelled *Tynemouth*, for the propelling machinery of which Mr. Mavor was responsible, was not a success. It is, however, gratifying to know that this failure was in no sense attributable to the electrical installation. The ship was built for trade on the Canadian canals and rivers, and had, as I understand, to be run economically at widely different speeds to suit, on the one hand, the legal requirements of the canal authorities and, on the other hand, the necessities of the St. Lawrence traffic. The Diesel engines which were used as prime movers for the electric generators failed to meet the widely different demands for power under these two very different service conditions.

Unfortunately, it would look as if the *Tynemouth* experiment had raised doubts in the minds of British engineers; for, whereas electric propulsion had its beginning in this country, we have allowed its development to be carried on largely by others. In particular, the United States of America have tackled this problem in no half-hearted fashion, and already there are thousands of electrical horse-power in turbo-generators either installed or being built for installation on board ships of the United States Navy. It is very significant of the confidence which our American friends, rightly or wrongly, place in this means of marine propulsion that one electrical manufacturing firm alone has on order complete equipments of turbo-electric propulsion for no less than seven battleships and four battle-cruisers of an aggregate shaft horse-power not far short of one million. The following are some of the arguments that influenced the American Naval Authorities in their decision to adopt this means of propulsion.

Electrical propulsion gives practically complete duplication, for with two turbines and two motors one or other of them could break down and still leave a means of propulsion. This is, of course, true also as regards direct-connected machinery, but in the case of the electric drive if a turbine breaks down the propulsion would still be twin screw; whereas under similar circumstances the direct-geared turbine or reciprocating engined ship would have to get along as best it could with one propeller.

Electrically-propelled ships fitted with motors having pole-changing connections can be run at cruising speeds under conditions designed to give as good economy as at full power; for when cruising one turbine can be run at full speed and under full load and can supply power to two motors running at half power, if a twin-screw ship, or to four motors running at quarter full power if a quadruple-screw ship. In this way each turbine can be operated under good load conditions and hence always under conditions designed to give good economy. Further, owing to the large speed-reduction permissible between turbine and motor, the former can be run at high velocity, an essential requirement for high economy in steam consumption.

This combination of good load conditions and high speed of turbine is a vital point so far as economy at cruising speeds on a battleship is concerned, and it is an advantage that any other form of propulsion will find it difficult to rival.

Speed can be maintained with much greater accuracy than with any other form of propulsion. This is of littl

importance to a merchant steamer, unless it be in a convoy, but it is not necessary to emphasize the importance of this to a battleship to anyone who knows the requirements of Naval Service.

The arrangement of the machinery is much more flexible, as the position of turbines and motors is not fixed in relation to one another. Again, the rapidity of operation when manœuvring is much greater.

Lastly, but not least, electric propulsion does not require separate turbines for going astern. Reversal of motion is accomplished by reversing the motors instead of bringing into use a turbine which, when the ship is going ahead, is all the time running idle.

As electrical propulsion entails a double transformation of energy which is absent in the mechanically-geared turbine installation, a transformation which may involve a loss of 10 per cent equally divided between the conversion from mechanical to electrical energy and the reconverting of such electrical energy back into mechanical energy, it is essential that if it is to show an advantage over its rival, the electrical method shall possess a much higher steam economy. This can only be obtained by a very high velocity in the turbo-generator and the supply to it of very highly superheated steam, as high indeed as can be obtained without unduly sacrificing the efficiency of the boilers.

It is only right to say that the advocates of the mechanically-geared turbine system have so improved its overall efficiency by introducing higher velocities in the turbine, highly efficient double-reduction gearing between turbine and propeller shaft, and a moderate degree of superheat in the steam supply, that electric transmission has little, if any, advantage over its older rival, except in such special applications as that of warship propulsion to which I have already referred. It is to be hoped that in the future such applications will become of increasingly diminishing importance and thus, unless the advocates of electric propulsion can show for it more decided advantages than it at present possesses over the mechanically-geared system, it would seem the latter system has little to fear in the much larger field of the mercantile marine.

Economy in steam consumption is not the only thing that matters; simplicity of construction and durability in all kinds of sea service have also to be considered. The greater complications introduced by the double transformation of energy, the addition of electric control gear, auxiliary generators for excitation of the alternators, forced ventilation of motors, heavier machinery, safeguards against accidental damage by water to the motors; all these matters must be taken into account when weighing up the pros and cons of electric versus mechanical transmission applied to marine propulsion.

The advantages of electrically-operated steering gear are becoming more and more widely recognized. As an auxiliary to the steam-driven gear, and as a substitute for the ponderous and slow-moving hand gear, electric steering has become standard practice in the British Navy. Some years ago one such gear was fitted, also as an auxiliary to the steam steering equipment, in a vessel belonging to the Orient Company. So successful was it that before long the steam gear had to change places with the electric gear and become an auxiliary to its more modern rival. The *Ormonde*, the latest addition to this same Company's fleet, is also fitted with two sets of steering gear, but in this case both are electrical—surely an excellent testimony to the reliability of the electrical drive. Not only in saving of operating costs through elimination of the losses through condensation of steam in long lengths of pipes, but also in the much more prompt response to the movements of the telemotor control operated from the bridge, is electric far ahead of steam steering gears. The system adopted in all the cases mentioned, and which appears to have practically superseded all other electrical systems, is that comprising a continuously running constant-speed motor coupled to a variable delivery pump, which in turn operates an hydraulic variable-speed gear.

This same power transmission gear is admirably adapted for application to boat hoists, cranes, gun turret and armoured-hood turning, and all such machinery where a positively-driven mechanism capable of being started, stopped, reversed, and controlled over an infinite range of speed is required. In addition to possessing all these attributes, this gear can be made to act as a gradual but positive brake, so that the driven shaft can be reversed at high speed almost instantaneously without shock. A single hand-wheel controls the whole of the operations of starting, speed controlling, reversing, braking, and stopping, so that the veriest tyro can be put in charge of it. In situations exposed to the weather, the electric motor and starter, together with its direct-coupled variable-delivery pump, can be placed snugly under cover below deck in any convenient position without reference to the driven portion of the gear, to which it is connected by a pair of small pipes. This is a most valuable feature which should appeal strongly to the shipowner, for not only is deck space saved but, what is of much greater importance, the motor and its starter can be kept under dry cover and thus be far less liable to break down than if exposed on a forecastle head to a sea breaking over them, as must necessarily be the case in the ordinary direct-geared electric winch. Another valuable feature of this gear is that the maximum horse-power of the driving motor can be utilized at wide variations of speed of the driven shaft. In this way a high and steadily applied torque can be given off at low speeds. This is a most valuable function in cases where an absolutely steady and powerful pull at creeping speeds is required, as in such operations as warping vessels into dock or training gun turrets on board ship. For heaving anchor or for handling large motor boats, and in all similar cases where careful handling by unskilled labour is necessary, this power transmission gear is ideal.

In the event of electric propulsion making headway, three-phase alternating current is certain to follow as a general system of distribution for auxiliary power and lighting, and where large motors are required to operate such auxiliary machinery as capstans, winches, steering gears, and similar reversible machinery, the electric-hydraulic system of power transmission in combination with squirrel-cage induction motors would form an ideal arrangement. For forced-draught boiler-room fans, where a direct-coupled adjustable-speed motor is required, direct-current motors will probably still be found the most suitable type. A supply for such motors, as possibly also for lighting and heating appliances, could be obtained either from the direct-current generators installed for exciting.

the fields of the main turbo-alternators or from separate auxiliary steam-driven generators.

On the other side of the Atlantic, I am told, three-phase alternating current is very much in favour for ship work, especially for installations on board oil-tankers. Incidentally I might mention that my informant tells me that the single-conductor uninsulated system, or, as we used to call it, the single-wire system, is considered to be bad practice in American electrical circles. Personally I am pleased to hear it, and I happen to know that it was only out of deference to its advocates in this country that provision was made for the continuance of its use when the Institution's Regulations for the Electrical Equipment of Ships were drafted.

Particulars of some of these three-phase installations were given in a paper recently presented to the American Society of Naval Architects and Marine Engineers The author states that the reason why alternating current is being adopted in oil-tankers in America is on account of the freedom from moving contacts possessed by squirrel-cage induction motors. Naturally such motors can be used with perfect security from any possibility to cause an explosion in spaces where oil vapour is liable to be present. Their control can, moreover, be centralized in the generator room, and in the majority of cases the starting gear need only consist of a three-pole switch in the circuit of each motor.

Next perhaps to wireless telegraphy, there is no piece of scientific apparatus installed on board ship to-day more interesting than the gyroscopic compass, or gyro-compass as it is usually called. Not many years ago it might have been thought that the last word had been said on the perfection of the magnetic compass. It had certainly been brought to a very high state of exactitude, or rather, I should have said, the knowledge necessary to correct its indications and make them applicable to exactitude in navigation had been brought to a high state of perfection, but the proverbial fidelity of the mariner's compass to the geographical pole, however much it may have been believed in by the average landsman, has been known by the mariner, to his sorrow, to be nothing more than a poor, weak tendency to point somewhere near a constantly shifting spot many hundreds of miles from the pole of the earth. In the gyro-compass we have an instrument which has not a tendency but a determination to point "true north," and that with far greater force behind it than the magnetic compass, no matter how delicately poised on its pivot, ever has to point to the magnetic pole. The gyro compass possesses none of the failings of the magnetic compass fitted on board a steel vessel and surrounded by electromagnetic apparatus, all more or less capable of powerfully seducing its needle from its allegiance to the magnetic pole. The principle of the gyroscopic compass has been known from at least the time when in 1851 the French scientist Foucault demonstrated the rotation of the earth by means of the gyro-top. It is said that Foucault's experiments were actually suggested by Lang of Edinburgh in the year 1836, but that they were never tried by him—another case, if true, of lost opportunities. The enormous constructional difficulties to be overcome before this principle could be turned to practical account prevented the few scientific men who attacked the problem from achieving anything but very feeble success. Indeed Hopkins, an American author and scientific demonstrator of great ability, was the only man who can be said to have achieved anything of importance in this direction until recent years—in 1906 in fact—when Dr. Anschütz for the first time evolved a practical gyro-compass, which two years later was tried successfully in the German battleship *Deutschland*. This Anschütz compass had one serious defect, in that it required two or three hours after putting the gyro-wheel in motion before really accurate observations could be taken. This drawback and other less important defects have been overcome in the Sperry gyro-compass, which can be made to point to "true north" within a few minutes after the gyro-wheel has been set in motion. It is almost needless to say that this gyro-compass has, on account of its superior merits, displaced the Anschütz compass in the British Navy. Owing to its necessarily costly construction it is hardly to be expected that it will come into common use in the mercantile marine, except perhaps in liners of the highest class. It is not my intention to discuss the theory or describe the structural details of this "triumph of inventive skill and fine mechanics." My real object in mentioning it at all is to point to the fact that without electric power in the form of alternating current to maintain the gyro-wheel in motion, the gyro-compass could not conceivably have been made possible as an instrument of precision. The gyro-wheel operates in a vacuum and forms the rotor of a three-phase induction motor, which in the case of the Sperry instrument runs at 8,600 r.p.m.

The future holds out great possibilities of ever-increasing usefulness for electric power on board ship. There is still room for investigation with a view to perfecting the methods adopted in, and in standardizing, the electrical equipment of ships so as to ensure greater immunity from breakdown and reduce the cost of maintenance. The conditions of sea service are so much more severe than those met with on land that a correspondingly higher quality of workmanship is called for.

Wireless telegraphy and submarine sound-signalling apparatus have played a most important part in minimizing the loss of life at sea from the barbarous acts of our enemies, and they will continue with increasing efficiency in the days of peace to bring succour to ships in distress and to warn them of impending danger.

With the exception of the small outfits installed in submarines and in a few of our large passenger liners, electric cooking has made little headway in our Navy and Mercantile Marine. The great improvements which have, however, been made on land installations, stimulated by circumstances for which the war is largely responsible, will assuredly have their effect upon this and many other recently developed applications of electrical science. These improvements should contribute to the material comfort of those who will go down to the sea in ships after peace reigns once more upon this disjointed and distracted world and when man will direct his thoughts to the creation of implements designed to benefit and not to destroy life and property.

# NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By R. H. Campion, Member.

(*Address delivered* 12 *November*, 1918.)

The activity of electrical engineers has been so progressive that it has led to the formation of branch sections; this multiplication should, however, not be looked upon as a sign of separation, but as pointing to the important position the electrical engineer has acquired in modern life. In order to appreciate this I would emphasize the fact that we are the only Institution that has set up Territorial Centres for the advantage of members and the holding of periodical meetings throughout the country. I do not think the importance of this is sufficiently appreciated by the various members in this county.

Another important development of our Institution is the various Committees which have been set up. The immense amount of time and hard work that have been put into these, demand that every section of the industry should help in every way possible to bring about the success that they deserve, and I hope when members of this Institution repeat a parrot phrase that has cropped up lately, "what has the Institution done for me," that they will remember the hard work that some of the members have done unselfishly for the good of the industry.

One of the drawbacks in the English character lies in its tendency to cling to precedent. In an entirely new set of circumstances the complete Englishman has usually no other resource than to bury himself in some library, searching for parallels from the past. This usually results in a considerable delay in taking any action, during which delay the set of circumstances which has given rise to research has in the rapidly moving conditions of the present time entirely altered, and the research and conclusions based upon it are rendered more or less futile. The basis upon which we have worked in the past—a plentiful supply of labour —has disappeared and it is doubtful if it will be re-established in a period of time short enough to affect the concerns of even the younger members of the rising generation.

Actually cheap labour can only be obtained where food is correspondingly cheap, and there can be little doubt that the various causes contributing to raise the price of food will take a considerable time to reach equilibrium. While an appeal to past achievements and experience is useful in matters of detail, very little can be gained from it to apply to the situation as a whole.

In the restoration of healthy conditions to the community, or rather the communities, affected by the war, the operations required, other than financial ones, come under the headings of Production and Transport. Sea transport is a question necessarily receiving very close consideration and, short of fresh propulsive methods for shipping, there is no part of the problem which is not likely to be intimately studied.

Land transport presents many more features, interesting particularly to the electrical engineer, and is a department which will require a period of almost violent activity to enable it to keep up with the supplies, external and internal.

It is to be expected that in conjunction with extensive works of building and restoration, a severe strain will be put upon means of transit already subjected to a long period of wear and tear. Although it seems probable that efficiency will be rather in the direction of utilizing existing roads, than in endeavouring to supplement them by hastily constructed new systems, there can be no doubt that a large demand for railway appliances of almost every description is indicated by the situation. A large demand will mean a considerable speeding up of existing means of output. A heavy demand on production can only be met when the supply of the requisite material is regular and constant and not subject to heavy fluctuations in price. We know that this stability of supply conditions can be ensured by an external control practically universal, but we have, as yet, no theories as to whether such an arrangement can be effected by internal control, neither have we any indication as to the effect which such control would have on trade conditions, i.e. whether it is possible to eliminate the speculative element from an industry like metal mining, or rubber growing. If it is necessary to have a central clearing house for materials used in the manufacture of electrical machinery, it should not be beyond the capabilities of the principal representative bodies of the electrical industry to organize such an institution. Without some such channel for supply, prices might seriously affect the work of reconstruction. While on this point of railway and general traffic, it may be as well to draw attention to the question of periodicities in alternating-current supply. When railways were inaugurated in this country, some happy accident, which it is preferable to designate as a wave of common sense, preserved us from a multiplication of track gauges. In the event of a recurrence of activity in railway electrification, it is eminently desirable that some investigation as to the most satisfactory current and voltage for the line be made before the country is dotted over with innumerable experiments and the grouping of different systems at interconnecting railway stations. We know the inconvenience and hindrance to industry which may be caused by differences in supply voltages and periodicities.

A short time ago we were continually having held up to us the example of trade rivals whose method of commercial conquest was always to adapt the product to the individual taste of the consumer. We are now inclined to think that this system, very pleasant, no

doubt, was only possible where the expense involved, and possibly the objects sought for, could be attributed to some other impulse than a commercial one, consequently goods supplied could not be compared with those purely on a commercial basis. To study thoroughly the conditions of a new country and decide what product is most suited to its needs, is only possible to a concern having large funds for advertisement. This is not altogether outside the question of transport, because the reason why we do not get materials from certain districts is again a question of carriage. No one not commercially interested cares very much how a railway is worked provided it is cheap and carries goods with rapidity and punctuality. In new countries all these things are possible, but as the railway is often the parent of the town, it is as well that the growing communities should be in a position to supply whatever they need in the way of motive power quickly and cheaply, namely, that to whatever system of supply they are introduced it shall not result in an expensive type of motor.

In its minor application to road transport, electricity will probably not seriously compete with the petrol motor except for suburban traffic, at any rate for some time. It may, however, develop with the petrol or gas motor in the dynamo-driven vehicle with motors on the axle. More will depend upon the durability of the petrol engine than on the electrical side of such a combination.

In sea transport, as, indeed, in every reviving industry, the great need is of course speedy construction. If the electrically propelled ship is to be a success, there must be no delay in the delivery of the machinery. However, the construction of a hull has not got down to a period such as to hasten the normal period of construction of suitable dynamos or motors. It is to be hoped that the introduction of electrical machinery in this application will result in considerable economies being effected in the application of the power generated. Present methods of propulsion may be largely improved ; in any case it is not possible to turn out a standard machine for anything in this line until the whole system has passed the experimental stage. In this connection the central body representing the interests of all sections of an industry can render very useful assistance. The precise nature of the material to be employed, and even the thickness, have been tabulated in the case of electrical cables for example, and the only variations which can be traced in different makes of cables are therefore those of quality and handling. A standard has been given for a procedure which, if carried out with reasonable care, will give an article suited to certain work. The relation of the carrying capacity of the conductor to the heating effect is equally vital, and in this the Institution Wiring Rules are universally accepted. It is thus possible, with some knowledge of the relative merits of the processes employed, to order cable from a code word or number covering all the details.

With another very important electrical product, namely, motors, this difficulty of standardizing is increased by the great variety of applications modifying the structure. During the past quarter of a century the development of the electric motor is one of the things that has been most prominent, and when one realizes the important part it plays in everyday life, the gradual way which it has been developed is one of the most interesting facts for those who have dealt with it. The different uses it has been put to have developed a variety of methods of transmission, many of doubtful economy. I think it is not sufficiently appreciated what amount of harnessing the electric motor has done and is going to do now that power supplies from some generating stations are over 75 per cent of the output ; therefore, so much prominence should not be given to the words "electric light," so often made up in the titles which date back to the nineteenth century. In motors, as in every other mechanical product, the question of actual assemblage takes a very important place. The simplest possible materials carefully put together, with due regard for the stresses to which they will be subject, will produce a more satisfactory machine than a higher class of insulation assembled by less skilled labour. It is therefore obvious that a machine upon the continuous working of which considerable issues depend, such as the motor of a converter, or a motor employed in some function vital to a ship, cannot be expected to be produced at a low price. On the other hand, if motors are to be adopted extensively and in the variety of mechanical appliances which will replace human labour in the minor details of life, a low price is not only necessary to render them popular, but is also indicated by the fact that breakdowns in such motors are more likely to arise from unskilled handling than from defects of manufacture. For instance, some motors are often subject to conditions of damp which would cause the insulation of any but the most expensive enclosed types to deteriorate, and the only way to remedy such conditions seems to be to teach by experiment that the installation of electrical machinery does not entirely consist in placing it where there happens to be a space for it. Thus we are involved in the supply of an expensive type made by the highest class of labour, and a cheaper type to prevent the haphazard buying of second-hand machinery more or less unsuited to the purpose for which it is required.

In classifying, some such arrangement as that adopted in rating cables, namely, Association and Non-Association, should be possible. The great advantage of anything like a standard type is of course the possibility of working to stock and establishing a complete record of the performance of certain sizes and grades, so that it may be possible to co-ordinate an entire plant without ordering one main part and then having to issue lengthy and detailed specifications to ensure the remainder working with it. At present the manufacture of details which should take place simultaneously with that of more important parts is often delayed until some information can be gathered nearly at the end of the job, and it is by no means uncommon to have the plant held up for the delivery of a starting-switch or some such accessory. The complaint of the manufacturer under the old conditions was that the consumer would not take the goods provided for him, but insisted on some original pattern which materially delayed con-

struction and increased the cost. In those days, of course, the consumer was a person of some importance. Under present conditions, the largest and most important consumer is, or was very recently, engaged in destroying products of all kinds. This condition we naturally hope is not a permanent one, though it has to be treated as a good deal more than a transitory upheaval. Even such interruptions as strikes are foreseen and provided for by astute organizations, but during their occurrence nothing is to be gained except experience. In a short time we shall revert to a state in which the importance of the consumer is measured by his powers of using the products he takes to manufacture some article to replace the present wastage.

We may expect, when peace is declared, reconstruction in every way—demand will be three or four times as great, and supply busy working out new methods. If it is necessary for everything (raw materials) to be dealt out, let us not fall into the lap of trusts, but put up a control fairly representative, developed from a body representing every type of interest in this industry, such as this Institution.

# PATENT LAW AMENDMENT.

The following Report of the Patent Law Committee was adopted by the Council in June last. The Report was also adopted, subject to a few verbal alterations, by a Conference of representatives of some 30 leading scientific and technical Societies, convened by the Institution of Mechanical Engineers. A deputation from the Conference waited on the President of the Board of Trade on the 10th October, when the Report formed the basis of the representations made to the Board by the deputation.

## REPORT OF COMMITTEE ON PATENT LAW AMENDMENT.

### Committee.

Mr. W. M. Mordey (*Chairman*).
The President (*ex-officio*).
Mr. A. E. Cachemaille.*
Dr. S. Z. de Ferranti.
Mr. J. Hunter Gray.
Mr. John Gray.*
Mr. H. H. Harrison.
Mr. S. Morse.
Mr. D. Murray.
Mr. A. P. Trotter.

* Representing the B.E.A.M.A.

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Although formed primarily to consider the 1917 Bill to amend the Patents and Designs Act, 1907, the Committee were broadly instructed to report on Patent Law Amendment. They have therefore included in this Report observations on certain matters that are not raised in the Bill.

So far as this Report refers to the Bill itself it is based on the 1917 Bill which was introduced and withdrawn last Session. It is to be reintroduced this Session in some form, but its contents are not yet known. It is certain that it will differ in some respects from the 1917 Bill.

The Committee have given full consideration to the proceedings at the meeting of members on the 28th February called to discuss the Bill, and to certain recommendations received from the Committee of the Newcastle Local Section.

### I. Introductory Statement.

The Committee consider it desirable to make a general statement setting out the main principles and considerations which have guided them.

It is common ground that invention is the basis of industrial progress, but invention must be encouraged, and, if the reward offered by the State takes the form of a monopoly for a term of years, such a monopoly must be of a kind that will encourage capitalists to assist in developing commercially the inventions in which they are invited to take an interest. Without capital, few inventions can be developed or even made. At the best, monopolies in the form of Letters Patent depending as they should on the question of novelty cannot be regarded as gilt-edged securities, but it is possible, by legislation and otherwise, to provide that those who expend thought or time or money in devising useful processes or products shall obtain in return for a real invention a true monopoly which cannot be revoked.

The Committee are convinced that the progress of invention during the past 25 years in this country has been much less than it would have been if proper encouragement had been given by legislation and otherwise. The effect of legislation as a stimulant or deterrent can hardly be over-estimated. It is a standard upon which public

opinion is largely moulded and by which it is guided. Legislation couched in language which expressly or by inference treats inventors as meritorious or unmeritorious must exercise profound influence on the industries all of which depend upon invention.

At no time in the history of this country so much as at the present has there been so urgent a need or so great an opportunity for placing invention in the most favourable condition to help industry, and it is with this conviction that the Committee have carefully considered the proposed Bill. They feel that the latter will not only not encourage, but will discourage, both inventors and capitalists, inasmuch as it adds to the already large risks of patentees and still further lessens the value of Letters Patent as securities for the advance of money to develop inventions. They are of opinion that every effort should be made to reduce, if not to remove, the number of weapons available to people here and abroad, especially the latter, for attacking patentees who own real inventions, and in many cases have spent much time and money on them.

### II. Patents Moratorium.

At their first meetings the Committee considered the representations made to the Council before the appointment of the Committee, that, as many points in the Bill affecting permanent legislation would take a good deal of time to consider, it was advisable at once to press on the Board of Trade the need for dealing adequately with patents as affected by the war. It was felt that there was much force in the suggestion made by Dr. de Ferranti that a short separate Bill was desirable to provide for an automatic moratorium or prolongation of patents to meet war conditions. The Committee are of opinion that an extension for a period equal to the total duration of the war should, on application, be granted in the case of those patents which were in force when the war broke out and are still in force when peace comes—that in the case of patents which have expired by lapse of time during the war the extension should be for a period equal to that from the commencement of the war to the end of the ordinary life of such patents—and that for patents, other than war patents, which have been taken out since war commenced, the extension should be for a period equal to that between the date of application and the end of the war. It may be said that any automatic extension would unduly favour war patents, but it must be noted that such patents would be unremunerative after the war and would therefore gain no benefit from extension.

Advantage was taken of an unexpected opportunity of making a representation on this matter to the Board of Trade. The Institution was invited by the London Chamber of Commerce to appoint a representative on a deputation of the Chamber which was to be received by the President of the Board of Trade on March 12th. This invitation was accepted, and at the request of the President of this Institution, the Chairman of this Committee attended a preliminary meeting of the Section of the Chamber and accompanied the deputation to the Board of Trade.

Although the deputation was mainly concerned with the Trade Marks Bill, 1917, it obtained a hearing for the recommendation by the representative of the Institution of a short Moratorium Bill for Patents. Sir Albert Stanley, in reply, expressed a view opposed to any extension of the life of patents for causes connected with the war, contending that such action would amount to making patentees a specially favoured class who alone were not to suffer by the war. And in any case he was not in favour of a separate Bill.

It is, however, satisfactory to note that in recently stating in the House of Commons that the Patents and Designs Bill is to be re-introduced this Session, he announced that it would contain clauses dealing with the life of patents, the working of which had been prevented during the war.

The Committee still think it would have been better to deal with this matter in a separate Bill.

Clause 7 of the Bill which amends Section 18 of the Act does not deal with the real difficulty. It provides that if a petition for the extension of a patent has, as a result of war conditions, not been presented within the prescribed period of six months before the expiration of the patent, the period may be extended by the Comptroller and it enables the Comptroller to take into consideration the fact that the war has deprived a patentee of some of the benefits of the invention—but this is the case in the Act. Under Clause 7 of the Bill the position still is that the extension can only be granted in the case of inventions of especial merit as before.

The Bill perpetuates the evils of the present procedure, which are such that the number of petitions for extension presented annually is under ten, and in no year have more than three patents been extended.

Something very different is needed to meet the war difficulty. The Committee hope that when the new Bill is framed it will deal suitably with this very important matter. No scheme of extension will be effective unless it is simple and inexpensive. The great majority of patents have, by reason of the war, been deprived of a considerable part of their useful term. To meet this condition a very general extension is desirable.

As regards the renewal fees for such extended period, the Committee's opinion is that these should be low, for two reasons: (*a*) the renewal fees will have already been paid, generally on unproductive patents, and (*b*) renewal fees involve no appreciable expense to the Patent Office. It is therefore suggested that these fees should not be more than £1 per annum.

### III. Compulsory Licences and Working of Patented Inventions.

*Clauses 1 and 2.*—These Clauses are intended to replace Sections 24 and 27 of the Act. Section 24 provided for the granting of compulsory licences under certain specified circumstances, and Section 27 dealt with the working of patented inventions. The latter section was introduced into the Act to compel foreign owners of British patents to work them in this country. It is very doubtful if it achieved its purpose in any single case, but it became a powerful lever with which foreigners could and did harass British patentees for some years. It was obviously to the interests of a foreigner (in most cases he was a German) to revoke patents belonging to a British subject so that he might freely flood the market with imported articles.

The Committee are of opinion that Section 24 of the 1907 Act with alterations, which are indicated below, would be

amply sufficient and much to be preferred to Clauses 1 and 2 of the Bill, which are not required.

Letters patent properly granted require that the invention should be new, should disclose sufficient invention, and should be properly and sufficiently described. If these requirements are complied with, it is in the opinion of the Committee wrong and illogical that the letters patent should be revocable on the ground of non-working, except with the consent of the owner. The only justification for revoking a patent is that it is invalid. If the owner does not exercise his monopoly so as to give substantial benefit to the public there are remedies other than revocation which can be applied. No remedy should be capable of being applied except in favour of someone who himself is ready and willing to do what he alleges and proves that the patentee has failed to do, namely, to give substantial benefit to the public. Such a person can under the Act apply for a compulsory licence, and non-working is a good ground for granting such a licence.

The possibility of revocation on the ground of non-working is an incentive to blackmailers and greatly detracts from the value of a patent as a security for financial support.

Even if there were no complete remedy other than revocation, which is not the case, it is doubtful if revocation should be possible, owing to the serious and disturbing influence it would have upon the progress of invention. It would penalize British patentees for the faults of foreigners. The same consideration applies to Designs.

The so-called "abuse of monopoly rights" has been during the last 20 years almost, if not entirely, confined to foreigners, especially Germans, who obtained British patents and did not work them in this country but held them for the sole purpose of stopping competition while they imported the patented articles. Obviously nothing could suit them better than the right to revoke British patents which interfere with their importation. The history of Section 27 of the 1907 Act is strong evidence of this, as practically most of the applicants under this section were foreigners or persons who desired only to import the patented article. This matter can be properly dealt with without revocation.

Before referring to the alterations which the Committee think it would be desirable to make in Section 24 of the Act to meet the case, the following short summary of the provisions of Clause 1 of the Bill is given and objections to them are indicated.

The title "Provisions for the prevention of the abuse of monopoly rights" is peculiarly unhappy in a Bill brought in at a time when there is a great need to encourage and foster invention so that this country may be in a position to compete successfully after the war.

The section purports to deal with such abuse on the application of "any person interested."

Five sets of circumstances are specified as constituting "abuse":—

(*a*) Non-working on a commercial scale in the United Kingdom without satisfactory reason.
(*b*) Prevention or hindering of working in the United Kingdom due to importation from abroad by or on behalf or with the consent of or without effective interference by the patentee.
(*c*) Demand for the patented article in the United Kingdom not met to an adequate extent and on reasonable terms.
(*d*) Any trade or industry prejudiced by refusal of the patentee to grant licences on reasonable terms.
(*e*) Any trade or industry prejudiced by conditions attached by the patentee to the purchase or use of the patented article.

The remedies that can be applied under the Section by the Comptroller of Patents are five in number :—

(*a*) He may endorse the licence with the words "licences of right," after which anyone can obtain a licence on complying with certain conditions.
(*b*) He may order a grant of a non-exclusive licence to the petitioner.
(*c*) He may in certain circumstances order a grant of an exclusive licence to the petitioner or to some other person.
(*d*) He may revoke the patent.
(*e*) He may make no order.

The rest of the section, consisting of many subsections, deals with machinery and directions for carrying the section into effect.

The course which the Committee would best like to see is that Section 27 of the 1907 Act should be repealed, and that Section 24 of that Act should be altered by enacting (1) that the petition should be made to the Comptroller of Patents with appeal to the Court who would deal with it. (2) That the provision enabling the patent to be revoked should be cancelled. This, it is believed, would be most in the interests of invention and of industry. The "reasonable requirements of the public" is an expression much more likely to lead to commercial development than the expression "abuse of monopoly rights." The former expression appears in the forefront of Section 24. It seems clear that provisions for compulsory licences are amply sufficient to protect the public from the danger of patentees holding up their patent rights. Such holding up as there has been has been largely done by foreigners, especially Germans, and simple machinery for obtaining licences from them would soon cause the evil to disappear.

The proviso at the end of Section 1, Subsection (2) of the Bill seems to be quite unnecessary, as implying intentional and widespread wrongdoing by inventors.

### IV. Articles for Food or Medical Purposes.

*Clause* 11 (*Section* 38*a*).—This Clause makes it impossible to patent articles intended for food or medicinal or surgical purposes or capable of being used for the production of food or medicine or surgical appliances.

The processes of making foods, drugs, medicines can however be patented. To illustrate the drastic effect of such provisions it is only necessary to mention the following examples of a few of the articles which would be unpatentable under the section :—

(1) All new machinery capable of being used in bakeries or for food production.
(2) Surgical instruments and appliances of all kinds.
(3) Electric motors capable of being used for driving dentists' drills, etc.

(4) X-ray tubes and other X-ray apparatus.
(5) Machines and apparatus useful in the manufacture of drugs and medicines.

The provisions of the section will prevent inventors and capitalists from developing industries which are admittedly in great need of stimulation and encouragement. It will tend to prevent many new developments which otherwise would surely take place after the war. It must not be forgotten that it is very difficult to induce manufacturers to take up unpatented inventions. This country is notoriously behindhand not only with inventions relating to drugs and the like, and surgical and therapeutic appliances, but also in their development and manufacture. Practically all the supplies of modern articles used in surgery and other curative treatment, for example, electro-therapeutic apparatus, dental material and surgical appliances of all kinds, have been imported from America and Germany where considerable industries exist in this class of apparatus.

There is no reason why this industrial development and manufacture should not be carried on in this country. Our position in medical and surgical science justifies all the industrial support that can be given to it.

The framers of the section in considering its effect from a humanitarian point of view appear to have overlooked the fact that the encouragement of invention greatly helps progress.

This Committee consider that the section should be eliminated from the Bill and suggest that the real objects of the section so far as it relates to drugs and medicines will be more readily accomplished by altering the present Acts relating to Foods and Drugs, especially in the direction of compelling the proprietor of a new drug to state on the container clearly the composition of the drugs or its ordinary chemical name in the case of a product to which a fancy or trade name has been given, as is the practice in the United States of America.

It is interesting to note that in the United States of America and the British Colonies and several other parts of the world no patent restrictions exist on the articles involved such as are proposed in the section.

### V. Approval of Clauses 5, 8, 9, and 15.

The Committee consider these Clauses of the Bill embody improvements—Clause 8 being the most important.

*Clause* 5 provides that where :—

"(*a*) an applicant has agreed in writing to assign a patent when granted to another party or a joint applicant and refuses to proceed with the application" ; or "(*b*) disputes arise between joint applicants as to proceeding with an application," the Comptroller under certain conditions may grant a patent to the other party or to one of the joint applicants.

*Clause* 8 provides that in any action for infringement, a patent otherwise bad, shall not be invalidated if it contains one good claim. At present a patent otherwise good is invalidated if it contains one bad claim.

*Clause* 9.—"In an action for infringement, the plaintiff shall be entitled to relief by way of injunction and damages but not to an account of profits."

*Clause* 15.—An assignment of or a licence to use a patent shall not be admitted in evidence in any Court unless it has been recorded on the Patent Office Register.

### VI. Term of Patents.

Clause 6 increases the term, which is now 14 years, to 15 years, with a proviso that it may be extended to 16 years if it is found expedient to secure greater uniformity with countries which may be parties to any international convention.

While the Committee would prefer that the term be 17 years as in the U.S.A., they recommend that at least the term should definitely be made 16 years as there would clearly be no objection in principle to that.

### VII. Suggested Extension of Provisional Term.

The Committee regret that the period within which a complete specification may be left, after an application accompanied by a provisional specification has been filed, has not been extended. Section 5 of the Act of 1907 reduced this period from nine months to six months, it is understood because the period of three months then remaining before the acceptance of the complete specification must take place was too short to enable the Patent Office to make its search as to the novelty of the invention and for the specification and claims if necessary to be amended.

With many inventions, especially those relating to complicated machines and apparatus, the present period of six months' provisional protection is entirely inadequate to allow of an experimental machine or apparatus being made or tested. This is not to the benefit of the patentee, who should have sufficient time to test his invention and to prepare a complete specification and claims which will adequately protect that invention. And it is not to the benefit of the public because they are thereby debarred from obtaining from the inventor such a full disclosure of the invention as will enable them to work it after the expiry of the patent to the best advantage. The Committee strongly urge that there should be a reversion to the old period of nine months with the possibility of obtaining at least three months' extension of this term on payment of a nominal fee, instead of one month only as at present. Thus the maximum period would be twelve months instead of seven months from the filing of the Provisional to the filing of the complete Specification.

It should be noted that in the United States the law gives the inventor what amounts to provisional protection for two years. This arises from the fact that the invention may have been in public use, or on sale, in the United States for two years prior to the date of application for the patent without in any way affecting the validity of the same.

### VIII. Suggested Extension of Term for Acceptance of Complete Specification.

The Committee also strongly urge that the time within which after filing the complete specification the same may be accepted should be extended. Such an extension will be necessary if the provisional term is extended to nine months as suggested above. Under the present Act (Section 6) (5) the complete specification must be accepted within twelve months of the date of application, with a

possible extension of not more than three months on payment of fees amounting in all to £6, or actually more than the fees payable on application for and sealing of the patent.

One reason for closely limiting the time within which complete specifications must be accepted has now disappeared. Previously, delay in the acceptance of a complete specification delayed the appearance of the illustrated abridgments of specifications, but this is no longer the case as under the new system now in force each specification is given a fresh consecutive number on acceptance, which ultimately becomes the patent number.

At present it sometimes happens that the examiner's search for novelty is not communicated to the applicant until three or possibly four months after the date of filing the complete specification.

If the complete specification is filed six months after filing the provisional specification, this leaves only two months within which the result of the search can be communicated to the applicant. If he resides abroad, or is temporarily absent from this country, this period of two months is usually insufficient—and for the more distant colonies quite insufficient for him to study the whole matter and consider what amendment of his specification or claims may be necessary and generally complete the prosecution of his application.

The Committee strongly recommend that the time within which the complete specification must be accepted should be extended as a minimum to eighteen months after the date of application, with the possibility of extending this term as at present by three months on payment of a fee which the Committee think should be much less than at present.

The restrictive procedure here as regards extensions compares very unfavourably with that in other industrial countries. Thus the period allowed in the United States is one year for filing an amendment to each official action of the Patent Office Examiner. On allowance of an application, even though it has taken several years to go through the Patent Office, there is a further period of six months within which to pay the final fee (corresponding to the sealing fee here) and secure the issue of the patent.

In Germany, on allowance of an application, even though it has taken two or three years to go through the office, the applicant may demand three months' delay of publication, and this cannot be refused, and he may obtain a further three months' delay all without payment.

These periods are very valuable because, having secured allowance of his application either in Germany or the United States, an inventor then has time to file applications for patents in such other countries as he desires without having such patents invalidated by the publication of the German or United States specification. In this country, contrary to what is the case in the United States and Germany, the applicant has only a partial search to guide him as to the novelty of his invention, and after securing the acceptance of his application at high pressure the utmost delay he can obtain within which to make a decision and file foreign patents before the British specification is published is three months, for which he must pay £6, assuming, of course, that it has not been necessary for him already to secure this extension of three months within which to meet the examiner's objections and secure the acceptance of his specification.

The view is held in some quarters that acceptance of a complete specification should take place at an early date in order that manufacturers here should be in a position to ascertain without undue delay what patents have been applied for, so that they may not suddenly find themselves confronted with a patent covering a process which they have adopted of an article upon the manufacture of which they have embarked. The Committee do not believe that the danger in question exists to any extent, but it could be guarded against by arranging that if not accepted after the expiration of 12 months—or 15 months if the provisional term be restored to 9 months as suggested—the complete specification should be open to public inspection *in the condition in which it was originally filed*. This procedure is already adopted in connection with applications for patents filed under the International Patents Convention [see Section 91 (3) (*a*) of the Act].

The applicant is not likely to cause unnecessary delay, since under Section 10 of the Act he does not enjoy the rights of a patentee until his complete specification is accepted.

IX. Patent to Bind the Crown (Section 29 of the Act).

The Committee regret that no substantial alteration is made in this section by the proposed Bill.

Notwithstanding the provision of the section that a patent shall have the like effect against His Majesty the King as it has against a subject, experience has shown that the administration of the proviso of the section has in effect practically nullified the operation of a patent against Government Departments.

Great dissatisfaction has for many years been expressed in connection with the operation of the section, and the Committee feel that inventors have been greatly discouraged in their endeavours to produce inventions of national importance.

It has been found practically impossible for patentees to obtain compensation for the use by or on behalf of Government Departments of their patented inventions. In many cases patentees have been asked to supply and have supplied working drawings, only to find that the latter have been distributed freely to their competitors, who have obtained most, if not all, of the Government orders for the patented article. The patentee has had no effective remedy, and frequently, after voluminous and prolonged correspondence with the Department in question, has had to abandon all hope of obtaining any compensation.

There is no method under the present legislation whereby the patentee can compel the determination of the matters in dispute between himself and a Government Department with regard to his patent. Inventors and patentees object to the Treasury, being practically in the position of purchaser, having the right to dictate the amount which shall be paid for the use of inventions. The Committee strongly recommend that the terms upon which an invention may be used by the Crown shall in default of agreement be decided by the High Court, and that the patentees should be entitled to apply to the Court for this purpose. On the hearing of such applications

the Crown and the Treasury can be represented, and the interests of all parties would be properly safeguarded—with due regard to national requirements, for example, as regards secrecy and otherwise.

The Committee believe that the adoption of the above procedure would greatly stimulate the development of inventions of national importance.

### X. Cancellation of Registration of Designs.

*Clause* 14.—The Committee point out that the amendment proposed in Clause 14 of the Bill will necessitate Section 56 of the Act itself being amended. Clause 14 proposes that *at any time* after the registration of a design a petition may be presented to the Comptroller for cancellation of the registration. Section 56 of the Act, however, provides that registered designs shall not be open to inspection for a period of at least two years after the date of registration except by certain privileged persons, and then only in the presence of an officer and on payment of a fee, and no copy of the design may be taken by the person making the inspection. These restrictions, the Committee believe, would very largely nullify the usefulness of the amendment proposed in Section 14.

### XI. Patents of Addition.

The Committee are of opinion that the proviso proposed to be added to Section 19 (3) of the Act should be as follows :—

> "provided that if the patent for the original invention is revoked or lapses for any reason, then the patent of addition shall, if the patentee so applies in writing to the Comptroller, become an independent patent, etc. (to end of proviso).

The Committee feel that this alteration is more fair to patentees than that the matter should be in the discretion of the Comptroller or the Court as proposed in the Bill.

### XII. Patent Fees and Profits of Patent Office.

The Bill makes no change in the present official fees. The 1907 Act by Section 65 and Schedule 1 allows maximum official fees of £155 on a full-term patent, but provides that lower fees may be prescribed by the Board of Trade with the approval of the Treasury.

At present the prescribed fees on a full-term patent are :—

| | £ | £ |
|---|---|---|
| On filing Provisional Specification ... ... | 1 | |
| „ „ Complete „ ... ... | 3 | |
| | £4 | 4 |
| or, on filing a Complete Specification ... ... | | 4 |
| On sealing of Patent ... ... ... ... ... | | 1 |
| Total (4 years' life) ... ... ... ... | | 5 |
| *Annual renewal fees* begin with £5 at the end of the 4th year, rise £1 a year to £14 at the end of the 14th year. Total Renewal Fees... ... | | 95 |
| Total fees for full-term patent ... ... | | £100 |

In the opinion of the Committee these fees are much too high and compare unfavourably with those in many other industrial countries, as is shown by the accompanying Table 1.

The Committee believe that low patent fees would lead to a great development in invention and that the country would benefit thereby.

It is probable that the favourable position occupied by the United States as regards inventions is largely due to the fact that patenting is cheap in that country—where patents are granted for their full term of 17 years at a cost in official fees of only £7 ($35). There are about 70,000 patent applications per annum in the United States as compared with about 27,000 here. And it is to be noted that in spite of the smallness of the fees the U.S. Patent Office is not only self-supporting but yields an average surplus of more than £40,000 per annum. Although the Committee prefer the British system of short-term patents renewable after 4 years by the payment of annual fees—and consider the present fees of £5 to cover the first 4 years of the life of a patent are reasonable—they feel very strongly that the renewal fees are much too high.

It is submitted that the present system by which large profits are made out of patent fees is wrong—that patents should be granted at the lowest possible cost consistent with the Patent Office being self-supporting—that the State should tax patents only through the income tax of patentees—thus taxing only successful inventors—that the encouragement of invention by lowering the cost of patents would almost certainly lead to a far greater return in income tax than the loss of revenue consequent on lower official fees.

It is thought probable that even in the very unlikely event of the number of patents not being increased the reduction of renewal fees would very soon produce as much as at present, by reason of the increase in the number of patents that would be kept up.

At present the mortality of patents is very great. Appendix E to the Annual Reports of the Patent Office shows that the percentage of completed patents kept up is as follows :—

| Year of life— | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|
| Completed Patents renewed, % | 39·5 | 28 | 21·9 | 18 | 14·2 | 11·4 | 9·4 | 8 | 6·2 | 4·3 |

*Patent Office finances.*—The average results of working the Patent Office for the 10 years 1907–16 are shown in Table 2 so far as they bear on the present question. They may be summarized as follows :—

| | £ |
|---|---|
| *Receipts.*—Patent fees on application including sealing ... ... ... ... | 92,574 |
| Patent fees renewal fees ... ... | 172,896 |
| „ „ Total ... ... ... | 265,470 |
| Receipts from all other sources ... | 45,641 |
| Total ... ... ... | 311,211 |
| *Expenditure.*—Total ... ... ... ... | 194,867 |
| *Annual surplus* ... ... ... ... ... | £116,344 |

Attention is drawn to the very large proportion of the total receipts represented by patent fees, and to the very large proportion of the latter that is made up of renewal fees. It will be understood that almost all the expenditure of the Patent Office on patents is incurred at the early stages of a patent—and practically none on the granting of renewals.

### XIII. Suggested Reduction of Renewal Fees.

The Committee recommend that in view of the large average surplus of £116,344 the cost of patents should be very substantially reduced. This recommendation is in accord with the principle set forth in Parliament by the Chancellor of the Exchequer, Sir Michael Hicks-Beach, in 1890—that while patentees should bear the cost of the Patent Office he did not think the country ought to look to the patent system as a permanent source of income.

It appears to the Committee that the best way to cheapen patents would be to reduce the renewal fees, leaving the system in all other respects unaltered.

A reduction of the renewal fees by one-half is strongly recommended. This would make the cost of a full-term patent :—

| | £ s. d. |
|---|---|
| To Grant and Sealing (as at present) ... ... | 5 0 0 |
| Renewal Fees ... ... ... ... ... | 47 10 0 |
| | £52 10 0 |

Even in the very improbable event of no increase taking place in the number of patents applied for, completed, and kept up, such a reduction—on the basis of the average of the 10 years 1907–16—would still leave a surplus of £29,896, thus :—

| | £ |
|---|---|
| Fees on application, including sealing (as at present) ... ... ... ... ... ... | 92,574 |
| Renewal fees reduced by one-half ... ... ... | 86,448 |
| Receipts from all other sources (as at present) ... | 45,741 |
| Total receipts ... ... ... ... ... ... | 224,763 |
| Total expenditure (as at present) ... ... ... | 195,867 |
| Surplus... ... ... ... ... ... ... | £29,896 |

Should the effect of the reduction now recommended be to produce a considerable surplus, it is suggested that such surplus should be used for a further reduction of the renewal fees. It is thought probable that in this way it might soon become possible to reduce again the upkeep fees by one-half, in which case the full-term fees would be :—

| | £ s. d. |
|---|---|
| To Grant of Patent... ... ... ... ... | 5 0 0 |
| Renewal fees ... ... ... ... ... | 23 15 0 |
| Total ... ... | £28 15 0 |

which would still be four times as much as the total fees on a 17 years' patent in the U.S.A.

In support of this recommendation by the Committee of a reduction of renewal fees by one-half, attention is drawn to the fact that Clause 2 (page 7, lines 35–38) of the Bill provides that patents endorsed "licences of right" shall be subject to such a reduction.

### XIV. Official Fees and Terms of Patents in the Principal Countries.

(Table 1.)

| Country | Fees on Application and Grant | Term Covered | Renewal Fees | Total Fees | Total Term |
|---|---|---|---|---|---|
| | £ s. d. | Years | £ s. d. | £ | Years |
| U.S.A. ... | 7 0 0 | 17 | None | 7 | 17 |
| Canada ... | 4 0 0 | 6 | 8 0 0 | 12 | 18 |
| Sweden ... | 1 2 6 | 1 | 40 17 6 | 42 | 15 |
| Italy ... ... | 0 8 0 | 1 | 53 0 0 | 53·4 | 15 |
| Switzerland ... | 1 12 0 | 1 | 53 8 0 | 55 | 15 |
| France ... | 4 0 0 | 1 | 56 0 0 | 60 | 15 |
| Norway ... | 2 5 0 | 1 | 62 5 0 | 65 | 15 |
| Belgium ... | 0 8 0 | 1 | 81 12 0 | 82 | 20 |
| U.K. ... ... | 5 0 0 | 4 | 95 0 0 | 100 | 14 |
| Denmark ... | 2 5 0 | 1 | 129 10 0 | 132 | 15 |
| Austria ... | 2 18 4 | 1 | 162 1 8 | 165 | 15 |
| Russia ... | 4 15 0 | 1 | 223 5 0 | 228 | 15 |
| Germany ... | 2 10 0 | 1 | 262 10 0 | 265 | 15 |

### XV. Summary of Patent Office Accounts.

(Table 2.)

*Average for 10 years 1907–16.*

| *Receipts.* | £ | Per cent of Total |
|---|---|---|
| Patent Fees ... ... ... | 276,840 | 89·0 |
| Designs Fees ... ... ... | 6,383 | 2·0 |
| Trade Marks Fees ... ... | 16,768 | 5·3 |
| Miscellaneous ... ... ... | 24 | 3·7 |
| Sale of Publications ... ... | 11,276 | |
| *Total* ... ... ... | 311,211 | 100·0 |
| *Expenditure* ... ... ... ... | 194,867 | |
| *Surplus* ... ... ... ... | £116,344 | |

*Analysis of Patent Fees.*

| | £ |
|---|---|
| Fees on Application ... ... ... | 26,976 |
| „ Completion ... ... ... | 50,663 |
| „ Sealing ... ... ... ... | 14,934 |
| | 92,574 |
| Renewal Fees ... ... ... ... | 172,896 |
| Ordinary Patent Fees ... ... ... | 265,470 |
| Other Fees on Patents (extension of time, amendments, licences, etc.) ... ... | 11,370 |
| Total Patent Fees ... ... ... | 276,840 |
| Fees other than on Patents ... ... | 34,371 |
| | £311,211 |

### XVI. Proposed New Tribunal.

The Committee desire to state their views upon a matter which, although it does not relate directly to the proposed

Patent Bill, has a very important, if not vital, bearing upon it, namely, the legal procedure by which all disputes involving scientific questions are determined.

The Committee are aware that recommendations on this matter have already been made by the Federation of British Industries, an Association which, it is understood, represents capital of some £2,500,000,000 sterling.

The Committee feel that it is due to the industries of the country that there should exist in the High Court of Justice a division specially constituted to deal with litigation involving scientific and technical questions. During recent years the application of science to industry has become so increasingly complex that such a division is more than ever essential.

Although the great ability of the judges of the Chancery Division and their willingness to try scientific cases are admitted, yet the views of the judges as to what is invention have varied to a degree which has made it nearly if not quite impossible for manufacturers to obtain definite opinions as to the chances of success in patent disputes. And the much larger field which embraces questions of industrial contracts is also in a very unsatisfactory state. There is, in the opinion of both parties to such contracts, no satisfactory tribunal to decide such matters.

If industry is to flourish to the fullest extent there must exist machinery for adjudicating effectively upon actions involving technical matters, and the Committee urge in the strongest manner possible that such machinery should be provided. It is probable that more money and more serious issues are involved in patent and other technical questions than in all other actions put together.

It is in the opinion of the Committee obvious that no adequate experience can be gained or proper consideration given by a tribunal which does not give its whole attention to technical disputes.

The Committee believe from their knowledge of the electrical industry that such a division is an essential requirement, and that it would greatly stimulate and encourage invention. The Committee further feel that any alterations in the law relating to Patents, Trade Marks or Designs should be made coincidentally with the constitution of such a division, in which case certain provisions of the Bill will require alterations and additions on which the Committee would desire to have an opportunity of submitting recommendations.

W. M. MORDEY,
Chairman of the Committee.

*20th June*, 1918.

# PROCEEDINGS OF THE INSTITUTION.

## 615TH ORDINARY MEETING, 7 NOVEMBER, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Annual General Meeting held on the 30th May, 1918, were taken as read, and were confirmed and signed.

The PRESIDENT: My first duty is a sad one, because I have to refer to the loss of three very prominent and much esteemed members of the Institution. You are all aware of the untimely death through accident while on duty of Professor Bertram Hopkinson. The name Hopkinson is enshrined in all our hearts, and Professor Hopkinson was a worthy son of a worthy father. I am quite sure that I shall be consulting the wishes of all the members if I ask them to pass a very sincere vote of condolence with Professor Hopkinson's widow and family and with his mother. The tragedy of his death was emphasized by the fact that it occurred on the 20th anniversary of the day on which Dr. John Hopkinson and his three children lost their lives in an Alpine accident. The coincidence is an extraordinary one; and when we remember that only a short time before the death of her eldest son Mrs. John Hopkinson lost, after a lingering illness through wounds, her youngest son, I am sure our sympathy must be of a peculiarly poignant character. Quite lately we have also lost an Associate who was well known to all of us and whose death we deeply regret, Mr. J. O. Callender. Finally, to-night we have learned of the death of Mr. Russell Clarke at the early age of 47. He also was a very valued Associate of the Institution. In these three cases I propose that we pass a vote of condolence with the members of the family, and I will ask members to signify their approval.

The resolution was passed in silence, all present standing.

The PRESIDENT: I should like to mention that at their last meeting, held three or four weeks ago, the Council decided to set up a Committee to consider the question of a memorial to those members of the Institution who have fallen in the war and made the supreme sacrifice. I am sure we all feel that there should be a worthy, conspicuous, lasting, and useful memorial of these men whom we all honour in our hearts, and we should like to see it take some tangible form. For this purpose a committee has been set up consisting of the President, the four Vice-Presidents, and a number of other members, drawn partly from within the Council and partly from without, who we know have suffered bereavement themselves. We felt that we could not get a body of men more likely to prepare a scheme that would commend itself to those who have lost relatives in the war than by going to those who themselves are sorrowing. I should also like to mention the setting up of what I think will be a most useful Committee, to be known as the Technical Co-operation Committee. That Committee will have referred to it all matters regarding the relations of the Institution with foreign countries. The main object is to secure interchange of experience between British electrical engineers and the engineers of allied countries, and also when any question of rules arises that we should endeavour to bring British and foreign practice into harmony. That matter will come up at a very early date in connection with the electrical equipment of ships. It is of peculiar importance to have uniform rules in connection with an installation that moves about all over the world; I need not emphasize the importance of common practice in regard to spare parts and so on. That is only one case in point, and we hope that this Committee will tend to bring together into closer unity the electrical engineers of the allied countries.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

*Benevolent Fund.*—Ll. B. Atkinson, L. Birks, S. E. Britton, F. H. Broomfield, M. Farrer, J. S. Hasdell, R. de Hollanda, F. W. Main, E. Parry, S. Simpson, A. M. Taylor, and The Diesel Engine Users' Association.

*Library.*—Messrs. Butterworth & Co., Ltd., A. T. Dover, The Director-General of Electric Exploitation in Tokyo, F. A. Halsey, The Institution of Heating and Ventilating Engineers, P. Kemp, J. W. Meares, The Comptroller of the Munitions Invention Department, Sir Isaac Pitman & Sons, Ltd., G. G. T. Poole, Messrs. J. Selwyn & Co., Ltd., and The Wireless Press, Ltd.

*Museum.*—A. R. Bennett and J. W. Wilson.

The Premiums * awarded for papers during the 1917–18 session were then presented by the President to such of the recipients as were present.

Mr. Ll. B. Atkinson, Member, then delivered the Tenth Kelvin Lecture, entitled "The Dynamical Theory of Electric Engines" (see page 1).

A vote of thanks to the lecturer, proposed by Mr. W. M. Mordey and seconded by the President, was carried with acclamation. After Mr. Ll. B. Atkinson had replied to the vote of thanks the meeting adjourned at 7.55 p.m.

* *Journal I.E.E.*, 1918, vol. 56, p. 332.

THE JOURNAL OF
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Vol. 57. JANUARY, 1919 No. 278.

# THE USE OF HIGH-PRESSURE AND HIGH-TEMPERATURE STEAM IN LARGE POWER STATIONS.

By J. H. Shaw, Associate Member.

(*Paper first received 22 February, 1918, and in final form 6 January, 1919; read before* The Institution *21 November, before the* North Midland Centre *9 April, before the* North-Western Centre *26 November, before the* North Midland Centre *27 November, before the* North-Eastern Centre *9 December, and before the* Scottish Centre *10 December, 1918.*)

All engineers responsible for the generation of power by steam are seeking more economical methods by which the energy contained in the coal can be converted into energy of a more convenient nature. The power required may be in the form of electrical, hydraulic, or mechanical energy; the most important to the majority of the members of this Institution is the first named, and this paper is written principally from the point of view of the engineer interested in the generation of electricity.

With the use of steam as a medium for carrying the heat contained in the coal from the boiler to the prime mover, it is unfortunate that, with the present knowledge of thermodynamics, the greater part of the heat in the coal is lost—a comparatively small portion up the chimney and the greater portion in the circulating water, via the condenser.

It may be possible in the future to eliminate some of this loss by the use of a substance, other than water, which will allow of the use of a greater temperature range. As an alternative, the gas turbine may offer the solution. As these alternatives have not yet approached the commercial stage, engineers are, for the time being, compelled to focus their attention on increasing the economy to be effected by means of plant using water as a heat conveyor.

It is apparent that in order to increase the heat efficiency of a steam plant, whose characteristics are that a constant loss is inevitable whatever the temperature and pressure, it is necessary to increase the working range of temperature and pressure.

The upper limit is perhaps the temperature at which metals rapidly lose their strength, and the erosive effect which the very hot steam will have on the blading of the turbine. The lower limit is generally decided by the locality of the power station. A works equipped with cooling towers cannot expect to obtain a lower bottom temperature than 75° F., and this only when the towers are amply proportioned and the ground space is not limited. A bottom temperature of 80° F. is more to be expected, which will give a 28-inch vacuum or 2 inches absolute pressure. A power station located near a cold river or the sea, where the temperature of the water during the greater part of the year is approximately 55° F., can efficiently be equipped with condensing plant designed for 29·1 inches of vacuum, i.e. 0·9 inch absolute pressure. With cooling water at a temperature of 60° F., condensing plant for vacua between 28·5 and 28·8 inches can be installed.

There is little doubt that the majority of power station engineers have given attention to the efficient utilization of steam at the lower ranges of temperature and pressure, and have been during the past few years considering the upper range. Here there is rather more scope for choice, but it appears that doubt exists as to whether it is the more economical to increase the temperature of the steam by superheating, or to increase the range by the use of higher pressures and a moderate amount of superheat. This question has been shelved to a certain extent owing to engineers being engaged on war work and thus unable to give the necessary time and attention to developing plant suitable for the higher ranges.

An interesting plant has been installed by the British Thomson-Houston Company at their Rugby power house, consisting of a B.T.H. turbine and a Babcock and Wilcox marine-type boiler, capable of a normal evaporation of 18,000 lb. per hour with feed water

at 80° F. (the working pressure being 350 lb. per square inch, the final temperature of the steam after passing the superheater 700° F., and the test pressure of the boiler 525 lb. per square inch). Good results have been obtained from the combination, and an inspection of the machine after about a year's operation showed no undue signs of wear.

At the Carville power station, Newcastle-on-Tyne, the latest section of the boiler house is designed for 275 lb. pressure, and at Glasgow the boiler pressure at the new works is to be 250 lb. per square inch.

A question that will appeal to all is " Will it pay ? "

A good case can be made out for a jump to 600 lb. pressure with a total temperature of 700° to 800° F., but this will involve a considerable amount of development charges being borne by the undertaking or undertakings which are the first to adopt such a pressure. On the other hand, it appears that practically all

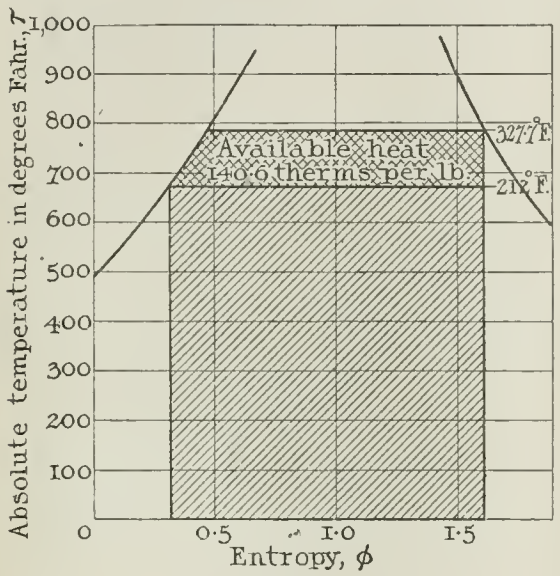


FIG. 1.

designs of existing apparatus can be so modified as to admit of pressures of 350 to 400 lb. per square inch. It would therefore seem that, to increase the working range of steam without the development of new designs, a pressure of 350 lb. can safely be adopted, and that if it is decided to increase the range the adoption of a pressure below this is akin to " hedging " the question.

When considering any results of tests on high-pressure or high-temperature steam generating-plant, it is essential that the tests on the boiler side and the tests on the turbine side be studied separately; further, it must be remembered that any results obtained on an extra-high-pressure boiler can be obtained and, considering the boiler apart from the economizer, surpassed on a similar and similarly equipped low-pressure boiler.

By the aid of the temperature-entropy diagram the gain due to increasing the working pressure and temperature ranges of the substance can be shown with advantage. Assuming frictionless adiabatic expansion,

Fig. 1 shows the amount of heat available in 1 lb. of dry saturated steam at a pressure of 100 lb. per square inch absolute (327·7° F.) expanding to 14·7 lb. per square inch absolute (212° F.), and is equivalent to 140·6 therms per lb. Figs. 2 and 3 represent the heats available per lb. of superheated steam expanding from 365 lb. per square inch absolute (736·4° F.) to 1·5 inches (mercury) absolute pressure (91·6° F.), and from 500 lb. per square inch absolute (736·4° F.) to 1·5 inches (mercury) absolute pressure (91·7° F.). The amounts of heat available are 470·2 therms and 485 therms per lb. of steam respectively.

The " Mollier " diagram, by means of which problems in adiabatic expansion can be graphically solved, has

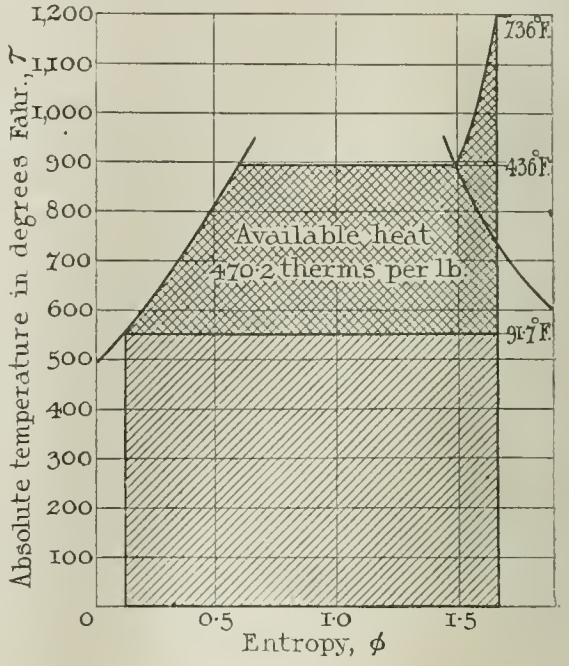


FIG. 2.

total heat as ordinates and entropy as abscissæ. True isentropic or unresisted adiabatic expansion involves no change of entropy, and would be shown on the diagram by a straight vertical line. As an example, assuming that steam is to be expanded adiabatically from 200 lb. per square inch absolute saturated to 1 lb. per square inch absolute, the amount of heat in the steam before expansion can be read directly off the chart or obtained from tables in regard to steam, the value being 1,205·4 therms. Following vertically down the chart until the pressure line 1 lb. per square inch is reached, it will be seen that the amount of heat still remaining in the steam is 866·70 therms, and that the steam is 76·5 per cent dry. Subtracting the latter value from the former, 1,205·4 − 866·7 = 338·7 therms, gives the heat drop or the number of therms available between the ranges above specified. As another example, with steam at 350 lb. absolute and superheated 250 degrees F. and at a total temperature of 682·4° F., the initial heat is 1,361·2 therms, the final heat amount-

ing to 922·5 therms at 1 lb. per square inch absolute; the heat drop in this case is 438·5 therms. Comparing the two examples, it will be seen that there is a gain of 99·8 therms per lb. of steam or water, or 29·5 per cent increase in available heat in steam at the higher temperature and pressure over the lower pressure, while only 12·9 per cent extra heat units were used in raising steam at the higher pressure over that required at the lower pressure.

The expansion that takes place in a steam turbine is not isentropic and is usually called adiabatic and resisted. Due to the friction, re-heating takes place during the passage of the steam through the nozzles and blades, and the mixture gains in entropy. The amount of this gain can be calculated with consider-

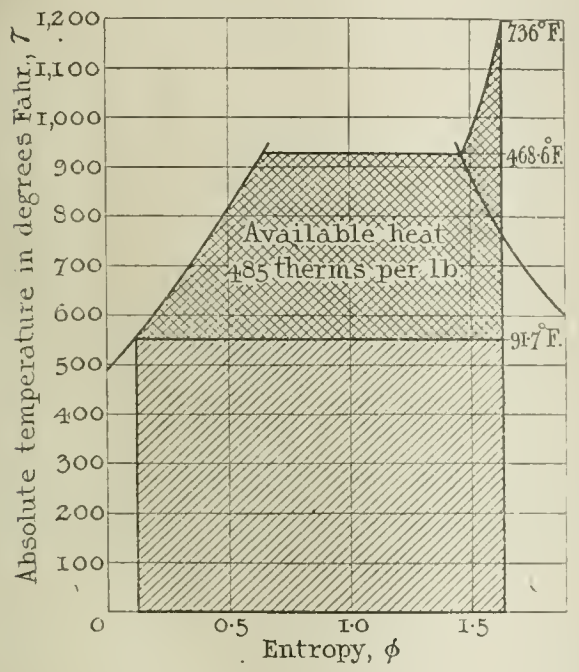


Fig. 3.

able accuracy by turbine designers, and approximately by the user. Mr. Goudie, in his book on "Steam Turbines," has calculated a series of curves by which he arrives at the "re-heat factor"; these curves are reproduced in Fig. 4, and can be used for multi-stage turbines and pressures between 150 and 200 lb. per square inch. The curves are likely to be low for higher steam pressures.

For a comparison between the cost of running a power station at 200 lb. pressure (gauge) and at 350 lb. pressure, Schedule 1 has been prepared. It is proposed to consider a riverside station, where the water is suitable for surface condensing. It is proposed to install 20,000-kw. sets, and coal is assumed to be within a reasonable distance; the cost of the coal, with a net calorific value of 10,000 therms per lb., is for the purpose of the schedule assumed to be 10s. per ton at the works. The incombustible contents of the coal would amount to 20 per cent. The average water temperature is taken to be 60° F., and the vacuum 28·5 inches, with the barometer at 30 inches. The overall efficiency of the boiler-house plant is assumed to be 77·5 per cent, which should be obtained with modern boiler control.

Turbine makers are not all in accord as to the efficiency to be expected from turbines of the size under consideration when working on high pressures. A well-known firm states that between 200 lb. pressure and 350 lb. pressure there will be a drop in ratio efficiency of 2½ per cent; other manufacturers state that a turbine can be built with the same efficiency at 350 lb. pressure as at 200 lb. There is no doubt that the increased density of the steam at the higher pressure will increase the internal losses in the turbine.

Martin, in his book entitled "Design and Construction

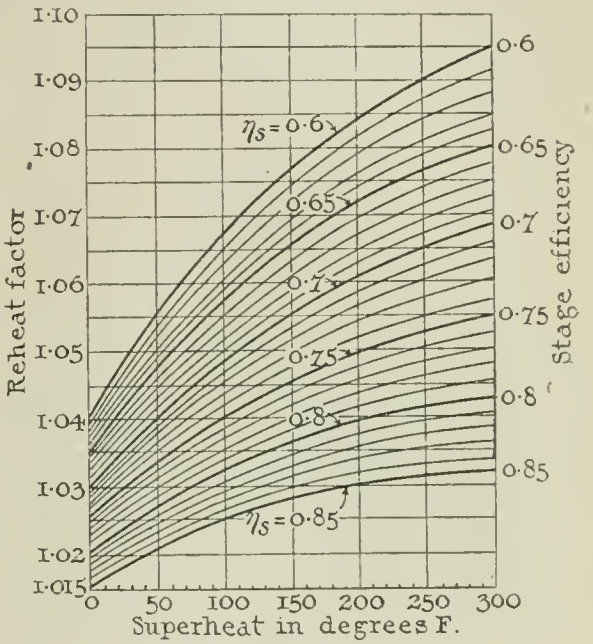


Fig. 4.

of Steam Turbines," gives Dr. Lasche's formula for the power absorbed by rotating discs as:—

$$\text{Power absorbed in kilowatts} = \frac{A}{5{\cdot}5}\left[\frac{\text{r.p.m.}}{1{,}000}\right]^3 \frac{d\,l}{V}.$$

where $d$ = diameter of wheel in inches;
$l$ = average length of blades in inches;
$V$ = specific volume of the steam;
$A$ = a constant.

The constant is unity for a wheel carrying one row of moving blades, and 1·2 for wheels with two rows. The formula is said to be valid for wheel diameters from 35 inches up to 47 inches, and for values of $l$ ranging between ¾ inch and 2 inches.

The author above quoted further states that "the resistance offered by a turbine wheel when at work is, however, quite different from its resistance when motored round; with a wheel at work and with com-

## SCHEDULE 1.

ABSOLUTE PRESSURE AT TURBINE EXHAUST, 1·5 IN. (MERCURY) (91·7° F.). CONDENSATE TEMPERATURE, 85° F.

| Steam Pressure at Turbine | 215 lb. per sq. in. (abs.) | | | | | 365 lb. per sq. in. (abs.) | | | | | | 500 lb. per sq. in. (abs.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Superheat of Steam at Turbine, ° F. | 100° | 150° | 200° | 250° | 300° | 50° | 100° | 150° | 200° | 250° | 300° | 268° |
| Total temperature of steam at turbine, ° F. | 487·9 | 537·9 | 587·9 | 637·9 | 687·9 | 486·4 | 536·4 | 586·4 | 636·4 | 686·4 | 736·4 | 736·4 |
| Total heat in steam from 32° F., therms per lb. | 1,265·0 | 1,293 | 1,319 | 1,345·5 | 1,371 | 1,249 | 1,278·5 | 1,307 | 1,335 | 1,363 | 1,389 | 1,382·7 |
| Heat drop per lb. of steam, therms | 379·1 | 391 | 403·4 | 416·1 | 429·2 | 402·4 | 415·4 | 428·7 | 442·2 | 456 | 470·2 | 485 |
| Ratio efficiency of turbo-alternator | 76·5% | 77·6% | 78·4% | 78·9% | 79·2% | 75·1% | 76·5% | 77·6% | 78·4% | 78·9% | 79·2% | 79·0% |
| Internal efficiency of turbine | 80·86% | 82% | 82·8% | 83·3% | 83·64% | 79·4% | 80·86% | 82·0% | 82·8% | 83·34% | 83·6% | 83·4% |
| Steam consumption of turbine, lb. per kw.-hr. | 11·77 | 11·255 | 10·79 | 10·402 | 10·04 | 11·30 | 10·746 | 10·265 | 9·85 | 9·491 | 9·17 | 8·913 |
| Total steam consumption of turbine, lb. per hr. | 235,500 | 225,100 | 215,960 | 208,000 | 200,800 | 226,000 | 214,930 | 205,300 | 197,000 | 189,800 | 183,400 | 178,300 |
| Heat rejected to condenser from 32° F., therms per lb. | 950 | 973 | 984 | 998 | 1,010 | 929 | 940 | 955 | 969 | 983 | 996 | 975·7 |
| Ratio of circulating water to steam condensed | 44 | 45 | 46 | 46·5 | 47·0 | 43 | 44 | 45 | 45·5 | 46 | 46 | 45 |
| Circulating water, quantity, galls. per hr. | 1,035,000 | 1,012,500 | 993,600 | 967,200 | 940,000 | 971,800 | 946,000 | 925,200 | 897,200 | 874,000 | 840,000 | 800,000 |
| Power for circulating pumps, b.h.p. | 163 | 160 | 157 | 153 | 149 | 154 | 149 | 146 | 143 | 138 | 133 | 124 |
| Power for air and condensate extraction pumps, b.h.p. | 89 | 86 | 83 | 80 | 77 | 86 | 82 | 80 | 77 | 74 | 72 | 70 |
| Power for boiler feed pumps, b.h.p. | 104 | 100 | 96 | 92 | 89 | 166 | 157 | 151 | 145 | 140 | 135 | 177 |
| Power for induced draught fans, b.h.p. | 222 | 220 | 220 | 216 | 212 | 218 | 212 | 207 | 203 | 200 | 195 | 186 |
| Power for small auxiliary motors, b.h.p. | 57 | 56 | 55 | 54 | 51 | 61 | 58 | 57 | 55 | 54 | 54 | 56 |
| Total power for auxiliaries, b.h.p. | 635 | 622 | 611 | 595 | 578 | 685 | 658 | 641 | 623 | 606 | 589 | 613 |
| Total power for auxiliaries, kw. | 530 | 515 | 510 | 495 | 485 | 565 | 540 | 530 | 515 | 500 | 485 | 510 |
| Net output to busbars, kw. | 19,470 | 19,485 | 19,490 | 19,505 | 19,515 | 19,435 | 19,460 | 19,470 | 19,485 | 19,500 | 19,515 | 19,490 |
| Heat in steam from temperature of hotwell, therms per lb. | 1,212 | 1,240 | 1,266 | 1,293 | 1,318 | 1,196 | 1,226 | 1,254 | 1,282 | 1,310 | 1,336 | 1,329·7 |
| Steam consumption per effective kw.-hr., lb. | 12·096 | 11·552 | 11·08 | 10·666 | 10·296 | 11·628 | 11·044 | 10·545 | 10·110 | 9·735 | 9·398 | 9·146 |
| Pounds of steam evaporated and superheated per lb. of coal, lb. | 6·394 | 6·25 | 6·121 | 5·90 | 5·88 | 6·48 | 6·32 | 6·18 | 6·045 | 5·91 | 5·8 | 5·83 |
| Coal consumption per effective kw.-hr., lb. | 1·891 | 1·848 | 1·810 | 1·78 | 1·751 | 1·794 | 1·747 | 1·706 | 1·672 | 1·645 | 1·62 | 1·569 |
| £ Cost of coal at 10s. per ton, generating $175·2 \times 10^6$ kw.-hr. | 74,100 | 72,400 | 70,800 | 69,200 | 68,500 | 70,250 | 68,100 | 66,750 | 65,500 | 64,400 | 63,400 | 61,400 |

plete admission there is no true windage due to the blades, whilst with partial admission the blades on the active arc are also free from windage."

In view of the above and the difference between the views of experts, it will be advisable to look ahead and anticipate that the efficiencies of turbines of the size under consideration will be improved in the near future. For the purpose of the calculations a turbine ratio efficiency of 80 per cent is assumed at both 200 lb. pressure and 350 lb. pressure, with the steam superheated 150 degrees F. and a constant vacuum of 28·5 inches. The corrections used for obtaining the turbine efficiency at different steam temperatures are taken from Mr. Baumann's paper.* An alternator of 20,000 kw. capacity can no doubt be built to give an efficiency of 97 per cent at unity power factor, thus making the turbo-generator ratio efficiency $0{\cdot}80 \times 0{\cdot}97 = 77{\cdot}6$ per cent. Assuming bearing and other friction losses to absorb 2 per cent, the internal efficiency of the turbine will amount to 82 per cent.

Schedule 1 shows the comparisons of coal, steam, and heat consumptions for a 20,000 kw. machine running

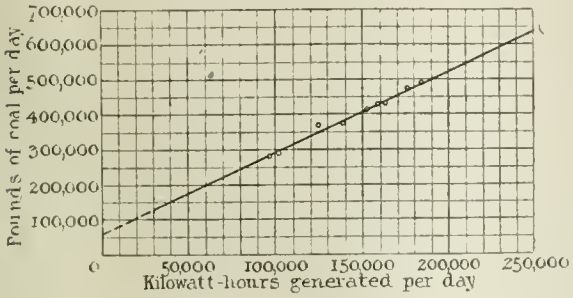


FIG. 5.—Station Conditions :—180 lb. per sq in. (gauge) ; 100 deg. F. superheat ; 28 in. vacuum ; 30 in. barometer.

under the conditions mentioned, at 200 lb. and 350 lb. pressure by gauge at varying superheats ; also at 500 lb. pressure absolute and 268 degrees F. superheat, at which pressure and superheat the total temperature will be 736·5° F., which is about the maximum temperature at present recommended for the materials now being used in turbine construction. Schedule 1 shows that the cost for coal when generating 175·2 million kw.-hours with a load factor of 100 per cent will be £64,400 at the higher pressure (superheat 250 degrees F.), and £69,200 at the lower pressure with corresponding superheat. This is a saving of £4,800 per 175·2 million kw.-hours, or 0·007 pence per kilowatt-hour. Unfortunately, a load factor of 100 per cent is impossible, and the conditions under which power stations are operated must be considered before even an approximate estimate of working costs can be arrived at.

An annual load factor of 50 per cent may mean full load for half the number of hours in a year, or anything between this and half load for the full number of hours in the year.

In order to avoid having to assume a curve of load and the necessity of calculating the consumptions at partial loads, a method of computation generally adopted for calculations of this nature, and one which is sufficiently accurate for this purpose, is to assume that the ratio of the station output to the total coal consumed is in accordance with Willans' law, i.e. a straight line.

Fig. 5 is plotted from results obtained at the Bradford Corporation's Valley-road power station for a number of days during the year 1917. On this curve the weight of coal used is shown to be 60,000 lb. per day plus 2·32 lb. per unit generated. The quantity of coal per day, i.e. 60,000 lb., is the no-load consumption of the works, and will include the no-load consumption of one turbo-generator. In order to make the calculations as simple as possible, it is proposed to deduct the no-load consumption of one machine (5,500 lb. of steam per hour) from the works' no-load consumption, and to assume an evaporation of 6 lb. of water per lb. of coal, and to call the figure so obtained the works' standing loss.

$$\frac{60{,}000 \times 6}{24} = \begin{matrix}\text{No-load consumption of works in lb. of steam per hour}\end{matrix} = \begin{matrix}\text{15,000 lb. of steam per hour}\end{matrix}$$

Deduct the no-load consumption of one machine

$$= 15{,}000 - 5{,}500 = 9{,}500 \text{ lb. of steam,}$$

and $9{,}500/6 = 1{,}583$ lb. of coal per hour.

To arrive at an estimated figure for the power stations under discussion, it is proposed to assume that the standing loss of the station designed for 200 lb. will be the same as for the Valley-road power station, i.e. 1,583 lb. of coal per hour. It will be fair if the same basis is taken for the plant at 350 lb. pressure, with 8 per cent added to the works' standing loss representing roughly the higher temperature of the steam at the higher pressure. Standing losses must be approximately proportional to the top temperature, as this affects radiation, boiler exit losses, etc.

For a 20,000-kw. set the no-load consumption will be approximately 22,000 lb. of steam, or 3,666 lb. of coal per hour. These figures plotted in conjunction with the steam consumptions shown in Schedule 1 give the total steam consumption at any load as

22,000 lb. + 9·54 lb. of steam per kilowatt-hour

for the plant operating at 200 lb. pressure, and

22,000 lb. + 8·6 lb. of steam per kilowatt-hour

and 3,729 lb. + 1·45 lb. of coal per kilowatt-hour for the plant operating at 350 lb. pressure and 250 degrees superheat.

In order to allow for changing over, for the period when two or more machines are temporarily running together at partial loads, for reduced efficiency in the boiler house due to adverse circumstances, and for the necessity of sometimes running the plant when it is not in the best condition, it will be advisable to add 5 per cent to the figures obtained for the load consumption and

* K. BAUMANN: "Recent Developments in Steam Turbine Practice." *Journal I.E.E.*, 1912, vol. 48, p. 708.

SCHEDULE 2.

| | | | |
|---|---|---|---|
| Steam pressure at turbine, lb. per sq. in. abs. | 215 | 365 | 500 |
| Superheat of steam at turbine, °F. | 300 | 251·6 | 219·4 |
| Total temperature of steam at turbine, °F. | 688 | 688 | 688 |
| Total heat of steam (from 32° F.), therms per lb. | 1,371·2 | 1,363·2 | 1,356·0 |
| Absolute pressure at turbine exhaust, inches (Hg.). | 0·9 | 0·9 | 0·9 |
| Heat drop per lb. of steam, therms | 454·9 | 480·7 | 495·4 |
| Ratio efficiency of turbine and alternator | 79·5% | 79% | 78·6% |
| Internal efficiency of turbine | 84·0% | 83·4% | 83·0% |
| Steam consumption of turbine, lb. per kw.-hr. | 9·44 | 9·00 | 8·77 |
| Total steam consumption of turbine, lb. per hr. | 188,800 | 180,000 | 175,400 |
| Heat rejected to condenser (from 32° F.), therms per lb. | 985 | 962 | 945 |
| Ratio of circulating water to steam condensed | 81 | 80 | 77 |
| Circulating water quantity, galls. per hr. | 1,520,000 | 1,460,000 | 1,350,000 |
| Power for circulating pumps, b.h.p. | 240 | 230 | 215 |
| Power for air and condensate extraction pumps, b.h.p. | 92 | 90 | 88 |
| Power for boiler feed pumps, b.h.p. | 84 | 133 | 180 |
| Power for induced draught fans, b.h.p. | 197 | 187 | 182 |
| Power for small auxiliary motors, b.h.p. | 62 | 64 | 66 |
| Total power for auxiliaries, b.h.p. | 675 | 704 | 731 |
| Total power for auxiliaries, kw. | 560 | 580 | 605 |
| Nett kilowatt output to busbars | 19,440 | 19,420 | 19,395 |
| Heat in steam from temperature of hotwell, therms per lb. | 1,331·2 | 1,323·2 | 1,316 |
| Steam consumption per effective kw.-hr., lb. | 9·715 | 9·26 | 9·04 |
| Lb. of steam evaporated and superheated per lb. of coal | 5·82 | 5·86 | 5·89 |
| Coal consumption per effective kw.-hr., lb. | 1·668 | 1·58 | 1·536 |
| Cost of coal at 10s. per ton, generating $175·2 \times 10^6$ kw.-hr. | £65,200 | £61,900 | £60,100 |

SCHEDULE 3.

| | 215 lb. per sq. in. abs. 250 deg. F. Superheat. 28 in. Vacuum. | 365 lb. per sq. in. abs. 250 deg. F. Superheat. 28 in. Vacuum |
|---|---|---|
| Total heat of steam (from 32° F.), therms per lb. | 1,345·5 | 1,363 |
| Heat drop per lb. of steam, therms | 401·3 | 441·6 |
| Ratio efficiency of turbo-alternator | 78·9% | 78·9% |
| Steam consumption per kw.-hr., lb. | 10·77 | 9·802 |
| Heat rejected to condenser, therms per lb. | 1,011·5 | 996 |
| Ratio of circulating water to steam | 63·5 | 62 |
| Power for circulating pump, b.h.p. | 432 | 385 |
| Total power required for auxiliaries, kw. | 730 | 700 |
| Lb. of steam per kw.-hr. on busbars | 11·15 | 10·2 |
| Lb. of coal per kw.-hr. on busbars | 1·79 | 1·675 |
| Cost of coal at 10s. per ton per $175·2 \times 10^6$ kw.-hr. | £70,000 | £65,200 |

Circulating water at 80° F. discharged from condenser at 96° F. Efficiency of boiler house, 77·5 per cent. Coal with a net calorific value of 10,000 therms per lb.

The head against which the circulating pumps have to work is taken to be 50 ft.

5 per cent to the no-load loss of the turbine, thus making the consumptions and costs as below :—

| | Maximum Load of 20,000 kw. and 50 % Load Factor 87·6 · 10⁶ units per annum | |
|---|---|---|
| | 200 lb. Pressure, 250 deg. Superheat, 28·5 in Vacuum | 350 lb Pressure, 250 deg. Superheat, 28·5 in. Vacuum |
| Works standing loss in tons of coal | 6,200 | 6,700 |
| No-load consumption of turbo-generators in tons of coal | 15,100 | 15,314 |
| Load consumption of turbo-generators in tons of coal | 65,300 | 59,867 |
| Total .. .. .. | 86,600 | 81,881 |
| Lb. of coal per unit on station busbars | 2·216 | 2·094 |
| Total cost at 10s. per ton .. | £43,300 | £40,940 |
| Cost of coal per unit .. .. | 0·119d. | 0·1122d. |

A further Schedule (No. 2) has been prepared, showing comparative coal costs of riverside stations working at

200 lb. per sq. in. (gauge), 300 deg. F. superheat, and 350 lb. per sq. in. (gauge) 250 deg. F. superheat, and 485 lb. per sq. in. (gauge), 220 deg. F superheat.

All the efficiencies and calorific values used in preparing Schedule 1 are used in preparing the Schedule above mentioned, so that they are directly comparative.

remaining items which make up the total works costs are not likely to be affected by the use of higher pressures and temperatures. Oil, waste, and water are practically unaffected; repairs and maintenance may be increased, but not to an appreciable extent. The capital cost of the plant is an item that may be affected to a considerable extent, but unfortunately the increased cost of turbines, boilers, pipes, etc., due to the use of higher pressures and temperatures cannot be given in a paper of this description. At a time like the present, when all manufacturers are experiencing difficulties in maintaining deliveries of standard articles, it is not to be expected that they will go into costs of special apparatus. Further, with the continued increases in wages, the cost of transportation, and the cost of raw material, it is almost impossible accurately to estimate any costs that are to remain good for a length of time. Whereas before the commencement of the war a 5,000-kw. turbine, alternator, and condenser could be purchased for £2·9 per kilowatt, a machine of 20,000-kw. capacity now costs £4·1 per kilowatt.

With regard to the practical difficulties, it is only to be expected that, before pressures of 500 lb. or 600 lb. per square inch are adopted, a radical departure will have to be made in present boiler construction. All square boxes and headers will be eliminated, the drums and tubes will be smaller in diameter, and the design of the boiler made more elastic. The type of boiler will no doubt assume the appearance of a flash boiler, with practically no steam or water reserve, and fired by gas on the surface-combustion principle.

For more moderate pressures, up to 350 lb. per square inch, the existing type of boiler can be modified and successfully used. At Carville power station Babcock

SCHEDULE 4.

| | | | |
|---|---|---|---|
| Steam pressure at turbine, lb. per sq. in. ab. .. .. .. | 215 | 265 | 315 |
| Total temperature of steam at turbine, ° F. .. .. .. | 688 | 688 | 688 |
| Superheat at turbine, ° F. .. .. .. .. .. | 300 | 281·6 | 265·6 |
| Total heat of steam (from 32° F.), therms per lb. .. .. .. | 1,371·3 | 1,368·6 | 1,365·9 |
| Absolute pressure at turbine exhaust, inches (mercury . .. | 1·5 | 1·5 | 1·5 |
| Heat drop per lb. of steam, therms .. .. .. .. | 429·2 | 440·3 | 449·1 |
| Ratio efficiency of turbine and alternator .. .. .. | 79·5% | 79·1% | 79·0% |
| Steam consumption of turbine, lb. per kw.-hr. .. .. .. | 10·010 | 9·805 | 9·625 |
| Total steam consumption of turbine, lb. per hour .. .. | 200,200 | 196,100 | 192,500 |
| Steam consumption per effective kw.-hr., lb. .. .. .. | 10·26 | 10·10 | 9·905 |

Schedule 3 shows the coal required, and power for auxiliaries, for a cooling-tower station working between 200 lb. per sq. in. gauge, 250 degrees F. superheat, and 350 lb. per sq. in. gauge, 250 degrees F. superheat exhausting against a back pressure of 1 lb. absolute pressure.

Schedule 4 gives the relative steam consumptions with steam at a temperature of 688° F., 215 lb. per sq. in. gauge, 265 lb. per sq. in. gauge, and 315 lb. per sq. in. gauge, exhausting against a back pressure of 1·5 inches of mercury or 28·5 inches vacuum.

The foregoing relates only to the cost of coal; the

and Wilcox marine-type boilers are being used at 275 lb. per square inch gauge pressure, and at the British Thomson-Houston Company's works at Rugby a Babcock and Wilcox boiler is installed and successfully working at 350 lb. per square inch. Further, Messrs. Babcock and Wilcox state that they have at present two boilers on order for a working pressure of 475 lb. per square inch with steam superheated to a final temperature of 700° F., and that they are quite prepared to supply boilers in their ordinary business for such pressure and superheat.

With higher steam pressures the temperature of

saturation is raised and, due to this, greater care must be exercised in the quality of the water used for the boiler feed. A feed water that is perfectly satisfactory at 380° F. in a modern tubular boiler might be quite unsuitable for use in a flash boiler. The quantity of air, $CO_2$, and oxygen will have to be kept down to a minimum, and also the non-soluble salts which are generally in the water discharged from an ordinary lime-soda water softener. A natural development, and one which is already taking place, is to heat the feed water under atmospheric pressure by means of live or exhaust steam in order to drive off the entrapped and dissolved gases as much as possible. According to the table below, extracted from Lunge's "Technical Chemist's Handbook," it is necessary to raise the temperature of the water to 100° C. before the quantity of air in the water is appreciably reduced.

SOLUBILITY OF GASES IN WATER.

*Volume of gas (0° C. and 760 mm. (mercury)) dissolved by one volume of water at the temperature indicated if the partial pressure of the gas is 760 mm. (mercury).*

| Water Temperature C. | O * | H * | $CO_2$ † | N † | Air * |
|---|---|---|---|---|---|
| 30° | 0·02608 | 0·01699 | 0·665 | 0·01380 | 0·01606 |
| 35° | 0·02440 | 0·01666 | 0·592 | 0·01271 | — |
| 40° | 0·02306 | 0·01644 | 0·530 | 0·01182 | 0·01503 |
| 45° | 0·02187 | 0·01624 | 0·479 | 0·01111 | — |
| 50° | 0·02090 | 0·01608 | 0·436 | 0·01061 | 0·01418 |
| 60° | 0·01946 | 0·01600 | 0·339 | 0·01000 | 0·01297 |
| 70° | 0·01833 | 0·01600 | 0 | 0 | 0·01216 |
| 80° | 0·01761 | 0·01600 | — | — | 0·01156 |
| 90° | 0·01723 | 0·01600 | — | — | 0·01126 |
| 100° | 0·01700 | 0·01600 | — | — | 0·01105 |

* Winkler. † Bohr and Bock.

The source of water for use in high-pressure plants will have to be carefully traced, and the treatment of the water should be such that a minimum of unsoluble salts remains in it after treatment. The purer the water the greater affinity it has for air, $CO_2$, and oxygen, and every care should be taken that it is not exposed to the air between the condenser and the boiler. In order to avoid such exposure to the air it is suggested that the feed pump should be an extension of the condensate pump and the condensed water pumped direct into the feed line.

The natural development of the turbine for higher pressures appears to be in a line with Parsons two-cylinder machine, with a flexible claw-type coupling between the cylinders and a thrust bearing for each cylinder. For very large sets, above 50,000 kw., the cross-compound turbo-generator will no doubt be used, the high-pressure turbine being attached to a generator and the low-pressure turbine to another generator. Each set can then be run at its most suitable speed, with resulting high efficiency. This arrangement will no doubt lead to re-heating the steam after it leaves the high-pressure turbine and before entering the low-pressure machine. Dr. Ferranti has already done valuable work on this subject, the results of which have unfortunately not been published.

The design of the condensing plant is not likely to be modified because of the use of high-pressure or high-temperature steam, but it must not be lost sight of, that with steam initially at the same temperature but at different pressures the plant using the high-pressure steam will reject less heat units to the condenser per lb. of steam used in the turbine

The steam pipes to be used in a station where both high pressures and high temperatures are employed will have to be very carefully designed.

A well-known tube firm on being asked their opinion as to the difficulties to be experienced with steam piping have replied that:—

"The thickness of both the tube and flange would vary slightly in accordance with the pressure. We should certainly recommend the tubes to be of our lap-welded process with flanges welded on, and in both cases the gauge of the piping and the thickness of the flange would naturally be increased according to the pressure to contend with.

"With regard to jointing material, we would suggest that corrugated rings and fibrine jointing compound would be most suitable and, for preference, for high temperature a nickel ring. Steel bolts to be used and not wrought iron.

"Regarding the temperature of 800°, we have had practically little experience of such a high temperature, but quite frequently we supply tubes for a temperature of 700° and, as far as our knowledge is concerned, we have not found that this high temperature has been the cause of any undue shortening of the life of the pipes; in fixing the thickness of mains, however, the reduction in tensile strength through the increase in temperature would of course be kept in view.

"As far as we can see, one of the principal difficulties with this high temperature will be with expansion, as the pipes will be thicker and naturally more rigid, so that it will be necessary to lengthen the expansion bends or any natural bends which are taking up expansion in order to meet the additional expansion in the mains, and therefore this point will have to be carefully considered in designing installations.

"The points of anchorage will have to be very carefully watched, as invariably in boiler houses there is nothing very substantial to anchor off at the essential points."

The question of expansion at higher temperatures will be of the utmost importance. For example, take the case of a steam pipe 100 ft. in length, and assume that the pipe had been erected at 60° F. It will be found that at a temperature of 388° F., equal to steam at 200 lb. gauge saturated, the expansion is 2·59 inches, while at 786·6° F., equal to steam at 600 lb. pressure and 300 degrees F. superheat, the expansion is 5·75 inches.

The expansion given can be readily taken care of if the designer can ensure that the expansion would

always take place lengthwise in the pipe range. Unfortunately, taking a boiler off a range will cause a considerable cross-strain to the main header, due to the connecting pipes cooling down and contracting.

It appears that the main steam connections of the boiler will have to be designed in a flexible manner, in order to relieve the main range of stress. Further, these connections should be of the manifold or header type, i.e. made up of many small pipe connections.

The specific volume in cubic feet per lb. of steam at approximately 800° F. and at pressures of 200 lb., 350 lb., and 600 lb. by gauge, are 3·47, 2·10, and 1·25 cubic feet per lb. Unfortunately the relative areas of the steam pipes cannot be reduced proportionately to the specific volumes, as the friction of the denser steam would cause undue pressure drop. Proportioned according to the density of the steam, a pipe to supply a 20,000-kw. set could have a diameter of 12 inches at 200 lb. gauge and 800° F. total temperature, and a diameter of 7·25 inches at 350 lb. pressure and 800° F. superheat, with a velocity of approximately 150 ft. per second. In actual practice the diameters would approximate to 14 inches and 10 inches for 200 lb. and 350 lb. respectively.

There is no doubt that a large proportion, in fact the major part, of the pressure drop in steam pipes as at present erected is due to the method of arranging ring mains and duplicate paths for the steam when certain parts of the main are down for joint making, and the provision of a duplicate path often so spoils the design that joints cannot be kept tight.

If the piping is designed on the unit principle, i.e. a number of boilers practically isolated on to one generating unit, a small equalizing main only need be provided at the end of the boiler house. Ample arrangements can be made for expansion with such an arrangement, and drainage is required at two points only in each section, at the turbine steam-separator and in the equalizing main. It could be arranged that steam would never enter or leave a pipe at right angles, and each branch would enter the main pipe at an angle of approximately 45 degrees.

From inquiries it is apparent that the boiler mounting and valve makers are quite alive to the possibilities of high-pressure and high-temperature steam coming into commercial use. One well-known firm report :—

"The highest steam pressure for which we have made valves is 400 lb. per square inch, and we are prepared to make the same for pressures up to 600 lb. per square inch.

"The highest temperature for which we have supplied valves is 700° F.

"The highest velocity in steam practice that we have met is 230 ft. per second."

They further state that with the limits mentioned above they have not found that high superheat has a detrimental effect upon steel or their non-ferrous alloy, which is used for the internal working parts of valves of their manufacture.

It is well known that cast iron when subjected to high temperature undergoes changes which in time causes it to distort and grow; there is also a chemical action taking place which causes the material to disintegrate and finally break away.

A 10-in. valve with a cast steel body and cast iron disc and seat, which was in service at the Bradford Corporation Valley-road power station for 8 years, had to be taken out of commission on account of the valve grooving and breaking. This valve had not at any time been subjected to a higher temperature than 480° F.

## SCHEDULE 5.

SHOWING COAL CONSUMPTION, COST OF COAL, AND THE AMOUNT OF CAPITAL THAT CAN BE EXPENDED TO ABSORB THE ESTIMATED SAVING PER 87·6 MILLION KW.-HOURS.

| Steam Pressure | 215 lb. per sq. in. (abs.) | | | | | 365 lb. per sq. in. (abs.) | | | | | 500 lb. per sq. in. (abs.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Superheat | 100° F. | 150° F. | 200° F. | 250° F. | 300° F. | 50° F. | 100° F. | 150° F. | 200° F. | 250° F. | 300° F. | 268° F. |
| 1. Coal consumption (lb.) per effective kw.-hr. at 100 % load factor and no station losses | 1·89 | 1·85 | 1·81 | 1·78 | 1·75 | 1·8 | 1·747 | 1·706 | 1·67 | 1·645 | 1·62 | 1·569 |
| 2. Coal consumption (lb.) per kw.-hr. delivered to busbars at 50 % load factor | 2·32 | 2·28 | 2·24 | 2·215 | 2·19 | 2·22 | 2·185 | 2·15 | 2·113 | 2·09 | 2·07 | 2·01 |
| 3. Annual cost (£) of coal at 10s. per ton per 87·6 million kw.-hrs. at 50 % load factor | 45,310 | 44,575 | 43,775 | 43,300 | 42,500 | 43,425 | 42,600 | 41,900 | 41,325 | 40,940 | 40,500 | 39,300 |
| 4. Estimated saving (£) per 87·6 million kw.-hrs., taking 215 lb. (abs.), 100 deg. F. superheat as datum. | — | 735 | 1,535 | 2,010 | 2,810 | 1,885 | 2,710 | 3,410 | 3,985 | 4,370 | 4,810 | 6,010 |
| 5. £ capital that can be expended for annual payments to absorb amount shown in line 4. Life of plant 15 years, and compound interest at the rate of 5 %. | — | 7,650 | 16,000 | 21,800 | 29,300 | 19,600 | 28,200 | 35,500 | 41,250 | 45,400 | 49,900 | 62,300 |

An American firm report as follows:—

"The increase of steam pressures above 200 lb. for commercial purposes has received impetus only during the last few years, and for that reason there is not a wealth of data to offer.

"It has been apparent to us for some time back that the trend of the engineering world was towards increased pressures and temperatures, and we have provided the market with material to meet the new requirements.

"We have designed a line of cast steel gate valves and special fittings for 400 lb. steam working pressure and total temperature of 800° F. and can furnish material for any steam pressure containing no greater temperature than above mentioned.

"It is not so much a question of pressure in the designing of a good valve or fitting as it is the temperature to which it can be subjected. It is a recognized fact that metals such as cast steel, cold rolled steel, nickel steel, and monel metal which are used in the manufacture of this class of material, show a decrease in elastic limit when temperatures higher than 750° F. are reached. The reduction of strength of the metal above 750° F. can, in a measure, be compensated for by proper design and liberal distribution of material, but other elements such as weight of piping, expansion and contraction, settling and water hammer must also receive serious consideration. The packing and gasket problems are also worthy of thought."

The question of the use of higher pressures is quite appreciated by the makers of economizers, who are prepared to manufacture economizers for 350 lb. boiler pressure or higher, either of their standard design, with the details modified, or of a design suitable for use as an integral part of the boiler, if necessary with horizontal and mild steel tubes.

### General.

It must be admitted that in order to attain a higher overall efficiency it is necessary to increase both the pressure and the temperature of the steam. An increase of pressure with a constant temperature would mean that the dew point is carried further up the turbine towards the high-pressure end, thus tending to accelerate blade erosion in the lower stages and a reduced stage efficiency of the turbine. Also the high-pressure blading of a turbine is considerably less efficient than the low-pressure stages, and although the losses in the high-pressure end are partly recovered in the low-pressure blades, it is apparent that to assume that a turbine for extra-high pressures can be built with the same efficiency as one for a lower pressure (within limits) is taking a hopeful view, and that there is justification for hesitation before adopting extra-high pressures on the part of managers responsible for the financial results of large undertakings.

The schedule on page 78 indicates that the coal consumption of a station is roughly proportional to the ideal cases worked out in Schedule 1; and such being the case, and taking a boiler pressure of 200 lb. per square inch by gauge as being representative practice for many power stations of moderate size, the results can be summarized as shown in Schedule 5.

In conclusion, the author would express his indebtedness to Mr. T. Roles, Chief of the Bradford Corporation Electricity Department, for permission to use information gathered from the Department's files, and to Mr. Abraham for his assistance in preparing the Schedules which entailed many tedious calculations.

## Discussion before The Institution, 21 November, 1918.

**Mr. J. S. Highfield**: The importance of adopting any possible means of saving coal is so great that it cannot be exaggerated. The author shows quite clearly that a pressure of 200 lb., which not very long ago was considered to be a high pressure, can be exceeded with advantage, and that the efficiency will be greater having regard to the capital cost. The experiments of the British Thomson-Houston Company, with which a number of us have been acquainted for some time, show exactly what the author indicates in his paper, viz. that a pressure of 350 lb. is quite workable and, in the conditions of high load factors assumed in his paper, advantageous. I anticipate that a great deal of care will be required in securing proper material to withstand the continuous application of the high temperatures involved. The greatest difficulty appears to me to be a metallurgical one. The provision of metals suitable for boilers, pipes, and turbine parts will involve much metallurgical research to obtain satisfactory results. I have no doubt that there will be repeated the common engineering experience that a striking advance in one direction will lead to equally striking discoveries in other directions. It is probable that, as plants are installed working at high temperatures, great advances will take place in our knowledge of steel, bronze, and other metals under the new conditions. Until there is more knowledge I should anticipate that numerous difficulties will arise. I have, however, no doubt that when economy is clearly shown, the difficulties will be overcome, as they have been in so many even more difficult instances.

**Mr. A. H. Ellis**: When first reading the paper I was impressed by the number of assumptions made by the author. The figures which he gives for a 20,000-kw. set are much better than we have had up to the present. The average steam consumption for some of the larger sets recently installed is about 11·5 lb., corrected for 200 lb. gauge pressure and 200° F. superheat, so that we have a long way to go before we get the figures down to what the author gives. I notice he says that in considering the results of any tests on high-pressure plant we ought to treat the boilers and turbines separately. I hardly agree with this, because if we gain anything on the turbines and lose it on the boilers we are no better off; and that we are not likely to get the same high efficiency on high-pressure boilers as on low is hinted at by the author himself. In regard to the behaviour of steel, etc., at high temperatures,

we are still, I think, very much in the dark. In a case that I know of, in a turbine that had been running for two or three years with a total steam temperature of about 550° F. the studs on the steam chest were found to be as brittle as glass, breaking off when given a slight tap with an ordinary fitter's hammer. Again we have to take into consideration that steam at a temperature of 700° F. at the turbine stop-valve means probably a temperature of 1,000° F. in the superheater, and we have very little knowledge of the molecular changes which take place at this high temperature with large pressures. In view of this it seems to me that before going to higher temperatures and pressures we ought to satisfy ourselves that it is safe to do so and that we know all there is to know under existing conditions. It is all very well to refer to the B.T.H. installation which is in good condition, but taking into consideration ordinary commercial work it is an altogether different matter. The method of anchoring the steam pipes, etc., at these high temperatures with the increased expansion would also have to be seriously considered. It seems to me that the saving may be offset altogether by the capital expenditure involved in providing the necessary plant. For instance, the author says that the condensate must be kept very clean and as far as possible uncontaminated by the atmosphere. That all means expense. It means an increase of power and upkeep, and the result depends on the saving which is made. I notice that the author also gives 77·5 per cent as the boiler-house efficiency. I think the boiler house deserves a little more consideration than the author has apparently given to it. A boiler house of 77·5 per cent efficiency is not obtained in this country, and I doubt anywhere else with continuous working, and especially with the coal which the author mentions containing 20 per cent of ash or incombustible material. The maximum efficiency I think he can obtain is 65 per cent at present, and that is very good indeed. If somebody can invent a boiler in which, instead of evaporating about 6 lb. of water per pound of coal, we can evaporate 10–12 lb., i.e. a 90 per cent efficiency, we shall achieve much more than by adopting higher temperature in the turbines, which will cause more trouble than we experience at the present time.

**Mr. N. Prentice**: All I wish to say is: do not use steam. For large powers I should try a Humphrey pump and water turbine. In 1911 I seriously thought of constructing a Humphrey pump to pump water against an artificial head consisting of an old boiler partly filled with water and compressed air to give a head, utilizing the water so pumped through a water turbine to drive an electric generator. Such a combination would in my opinion give the efficiency of an internal combustion engine without the lubricating and other internal combustion troubles, and would altogether be a simpler plant than with a steam turbine. I was advised to hold my hand as Messrs Siemens-Schuckertwerke were building a 1,000-h.p. set on these lines, and I now regret I did not go on with my proposition.

**Mr. H. M. Sayers**: I first used steam for electric lighting about 35 years ago, at what was then considered to be the rather high pressure of 120 lb. per square inch. The engines were non-condensing. By dint of a great deal of trouble with stokers, the treatment of the feed water, and the constant checking of the coal, both quality and quantity consumed, I thought I had done well when I obtained an output which may be defined as one 10-ampere arc lamp working for an hour for a boiler-house consumption of $5\frac{1}{2}$ lb. of Welsh coal. The last generating plant I was connected with gave a kilowatt-hour for just over a kilogram, say $2\frac{1}{4}$ lb., of anthracite peas or a little more of coke, through the medium of a gas producer and a gas engine. I cannot help thinking that however much progress has been made in the use of steam, and however much room there may be for the more economical use of steam, we are faced with the difficulty that we have to throw away the heat of evaporation of the steam, which represents a very large proportion of the total heat units in the coal. Having regard to the nature of the materials at our disposal for boilers, for steam pipes, and for turbine blades, a limit to practicable temperatures and pressures may soon be reached from the point of view of wear and tear. It seems to me that the line of progress for the best utilization of fuel is either with the internal combustion engine, perhaps not in the form we know it to-day, or in some such development as Mr. Prentice mentioned. In that direction there is great room for economy. A Diesel engine will give a thermal efficiency of slightly over 40 per cent at a good load. Is there the slightest prospect with any steam plant of getting near that? We cannot of course make 20,000-kw. Diesel engines to-day. It is also true that the high compression used in the Diesel engine has many disadvantages, and that Diesel or other plant using such high pressure involves heavy capital cost. Still that does seem to be the proper line of advance.

**Mr. P. V. McMahon**: I should like to ask the author a question with reference to the equation given on page 77, where he says: "These figures plotted in conjunction with the steam consumptions shown in Schedule 1 give the total steam consumption at any load as 22,000 lb. + 9·54 lb. of steam per kilowatt-hour." I do not know whether I have plotted the curve rightly but I can only make the second term 9·3 lb.

**Major A. M. Taylor**: I think the author has done insufficient justice to the cause for which he pleads. I will attempt to show, by a profit and loss account, taking the author's own figures (at the foot of columns 4 and 10 of Schedule 1) that financially the use of high-pressure steam would not be successful unless a load factor of nearly 100 per cent could be realized. In the "Creditor" column I should put the saving for a 50 per cent load factor $(50\% \div 100\%) \times £4,800 = £2,400$; and in the "Debtor" column:—

(1) Life reduced from, say, 15 years to, say, 10 years, and consequently increased depreciation from, say, $7\frac{1}{2}$ per cent to 10 per cent per annum. Taking the capital cost of boilers, pipework, turbines (excluding cooling towers or condensers) at, say, £5 per kilowatt, or a total of £100,000, $2\frac{1}{2}$ per cent extra depreciation on this would mean £2,500 per annum.

(2) Increased radiation losses (standing). Take 10 per cent on 6,200 tons of coal at 10s.=£310 per annum.

(3) Ditto on turbo losses, 10 per cent on 15,000 tons=£570 per annum.

The total "Debtor" account is therefore £3,560 per annum. There is thus a loss of £1,100 per annum. With a higher load factor there would undoubtedly be a saving; but, on the basis of the two columns of Schedule 1 selected by the author, we should not get a saving until nearly 100 per cent load factor was reached. Have I taken the extra depreciation too high? Even if only 1½ per cent additional depreciation were taken—corresponding to a reduction in life of from, say, 15 years to 13 years—the "Dr." and "Cr." accounts only just balance at 50 per cent load factor. I am sure nobody will say that 1½ per cent extra depreciation is too much to allow. I should like to ask why the author has not compared, say, column 1 of Schedule 1 with column 12. It seems as though in comparing only columns 4 and 10 he has not sufficiently stated his case. If the engineering difficulties can be overcome up to column 10, may we not hope they can also be overcome up to at least column 11? It is not clear why the author has given in Fig. 1 an entropy diagram for only 100 lb. pressure and without any superheat, and then in Fig. 2 jumped to 350 lb. pressure and 300 degrees superheat. The author seems here to be overstating the case just as much as he has understated it in Schedule 1. I submit that Fig. 1 should have been got out for the conditions of column 1 of Schedule 1, and then we should have had a visual representation of the gain in available heat between column 1 and column 11. It is disappointing that the gain between Fig. 2 and Fig. 3 is so small; it does not encourage one very much to face the difficulties of the increased pressure. In any case we must thank the author for clearly putting on record the case for and against the innovation.

**Mr. G. W. Partridge:** The question of the use of high-pressure and high-temperature steam is a most important one. Speakers to-night have referred to the alteration in the molecular condition of steel pipes and boiler plates due to high temperatures. In my own experience we have had trouble with our steam pipes apparently due to high temperatures. I have seen steam pipes taken out of a range for examination when a light blow with a hammer has broken the flange off the pipe, showing that crystallization has taken place round the whole flange. Future users of steam at high temperatures and high pressures must carefully consider the design and construction of apparatus. In Schedule 1 the author shows rather a low figure for the pounds of steam evaporated per pound of coal. I should have thought he could have got a figure of over 7 lb. without much difficulty. He also suggests the question of dealing with the feed water of a station by means of a Lancashire boiler. At my own station the whole of the make-up feed water for nearly two years has been served into a Babcock and Wilcox boiler, the rest of the boilers receiving only pure condensate. By this arrangement all losses in blowing down have been saved, together with the cost of labour, etc., in cleaning the boilers. I believe a similar arrangement has been in use in Holland.

**Mr. W. R. Cooper:** I notice that the author expresses his results in pounds of coal. Where close comparisons are in question it is preferable to use thermal units as the basis, so as to have a perfectly definite unit; a pound of coal is necessarily less definite unless well defined. In the present paper the coal is taken as having 20 per cent of ash, which is very high and seems uncalled for in a general comparison, although it may be used in a particular case. The author's figure of 77½ per cent for boiler efficiency has been attacked, but I think it can be justified. It is common knowledge that figures quite as high as this are obtained in this country, and it is doubtful if results such as those at Connors Creek (U.S.A.) could be obtained if the boiler efficiency were much lower. Here over a period of two years' working, the number of therms per kilowatt-hour available at the switchboard is rather less that 20,000, and if economizers were used the figure would come down to about 18,000. This is on a 40-50 per cent load factor. The saving in coal shown by the author does not appear to leave much margin for higher costs in maintenance and capital charges. I notice he suggests that flash boilers might have to be used and that careful softening of the water would then be necessary. Judging from personal experience with semi-flash boilers as used in White steam cars, I am not sure that this precaution would be necessary. Such boilers showed no deposit when fed with unsoftened London water.

**Mr. P. Rosling:** I notice that the author has taken the cost of coal at 10s. a ton. I do not know when we shall buy coal at such a figure as that again. To make the scheme more attractive it would be better to allow for coal at 20s. a ton.

**Mr. E. T. Williams:** The conclusion I draw from the author's remarks is that there is nothing in the paper to justify extra-high steam pressures. I think there are so many unknown factors in dealing with high-pressure steam that we shall have to go very carefully and slowly. Anything exceeding 300 lb. at the present time is, in my opinion, problematical. One advantage of using pressures of, say, 250 lb. and superheat, is that we can control the temperature of the steam, whereas if we use high pressure without superheat, as dealt with in the paper, we have not the same control of the temperature. In the present state of evolution, discoveries may be made whereby the control of the temperature of steam may become very important. I think the time has come when many more experiments ought to be carried out with gas under boilers, and also in using oil and tar. I should like to have heard the author discuss those problems, because it seems to me that quite different results might be obtained as compared with using coal, and this information will be important when oil and tar are obtainable at reasonable figures, as we hope they will be in the near future. Then I think the capital charges have not been sufficiently emphasized. At one station with which I was connected for a number of years, we were constantly experimenting with the coal consumption, and that station for a time

held the record in the country for the lowest cost of coal. There were two sides to the experiment. In the first place we worked the boilers at the greatest possible output, ascertaining the results that were then obtained, and in the second place we worked the boilers at the most economical figure, because it was found in that particular installation that the economical figure was not the figure of the highest output. Finally, the best conditions were obtained when we overran the boilers for the peak and worked them at their economical loading during the remaining hours. I think there is a great deal of room for experiment to see whether it is not possible to make central station boilers work so that the output for short periods, even at some loss of economy, can be very considerably increased, and run them for the longer hours at the more efficient figures. With reference to the experiments referred to in the paper, I think we want to be very guarded in the deductions we draw from special experiments compared with working experiments. At another station with which I was connected we made what I will call some special experiments with water-tube boilers, the results obtained being the best that had been produced up to that date. The results were published in the papers, but as one of the engineering staff I felt it ought to have been made clear that such figures could not be taken as a guide for working conditions. Everything was prepared for the special circumstances, and certain results were obtained. Those results were interesting scientifically but were not a reliable guide from a working standpoint. I think we have to face the fact that the maintenance charges with higher pressures will also be higher. The author mentioned in his opening remarks that the boiler makers said the problem of using extra high-pressure steam was a turbine makers' question and the turbine makers said it was a boiler makers' question. I think the time has now arrived when it should be the country's question, and I hope that the new Commissioners will see to it that all these questions will be considered.

**Mr. P. F. Allan:** I am one of many present who wish that the author had been able to make a better case for high-pressure steam. I agree with Major Taylor's remarks to the effect that the influence on the capital cost, and the influence of that on the cost per unit, which is, after all, the point we are concerned with, are likely to be very much greater than seems to have been considered. Although some of the speakers have mentioned maintenance, none of them have laid sufficient stress on the fact that maintenance as a rule is a fairly large proportion of the cost per unit, and that it is likely to be much increased if higher pressures are used. I do not know that I agree with the fears expressed by several speakers as to the difficulties that are likely to be experienced in obtaining steels and other metals to stand up to higher temperatures with safety. I think possibly a great deal more has been done during the war in the way of experimenting with new steels, new materials, and new methods of dealing with them, than most people realize, and I think that the problem will probably be tackled a great deal more easily now than if the past five years had been years of peace instead of war. With regard to the troubles which are anticipated in regard to crystallization of pipes, etc., I think the President will agree with me that possibly higher pressures are now used at sea than on shore, that the pipes are subjected to worse usage generally, and yet it is found that the higher pressures used can be dealt with and have not so far enormously increased the troubles usually experienced. Therefore one may well hope that, as steam pressure has not advanced so rapidly as, for instance, the use of higher electrical pressure, there is probably, from the technical point of view, scope for increasing the pressure without the fear of great troubles ensuing. I feel that the greatest trouble of all that we have to contend with is that of cost. I certainly agree with Major Taylor that the figures the author has produced do not look very hopeful. Whether they can be improved or not I do not know. After all, the coal cost per unit, even in the most modern stations with low capital cost per kilowatt, is not yet the greater part of the total cost, and consequently we have to make a tremendous saving in the coal cost before we can materially affect the total costs, especially if at the same time the capital cost and maintenance costs are increased. I agree with a previous speaker that the possible increase of efficiency of boilers and turbines must be taken together. I cannot see what we are to gain by treating them separately. If, as has been said, any increase in the efficiency of the turbine is to be met by a decrease in the efficiency of the boiler, or, what amounts to the same thing, a very great increase in cost, then I am afraid we are merely wasting time by discussing the matter. I agree with another speaker that a very great deal has yet to be done in connection with the use of oil and gas under boilers, and I have very great hopes that they will give us an opportunity of reaping greater benefits from increased pressure than may be the case with coal, but I do not feel that we are on the verge of handling very large powers generally all over the world by means of oil engines or internal combustion engines of any kind. Not only is there the difficulty that we are not able at the present time to get the high capacities wanted for low operation costs, but it must be remembered that low speed and capacity mean enormously expensive electrical plant and buildings, and also that in many cases we should be prohibited from using the high potentials which we desire to employ.

**Mr. F. W. Leevers:** I also should like to see more attention given to the steam-raising as compared with the steam-using side of a station. Generally the valves are a source of trouble. About 14 years ago for the Neasden Metropolitan power house I tested valves operating at 180 lb. pressure and 180 degrees F. superheat to double the working pressure plus the superheat. The principal troubles developed at temperatures of about 600° F., in regard both to effect on metals and to packing and expansion. In those days we used cast-iron shells and parallel gates. The results were disastrous, and time so dragged on in the effort to secure a satisfactory article that finally we started the station up on German-made valves. In looking over present-day types I do not think a great deal of

improvement has been made, so far as withstanding high temperatures is concerned. Fourteen years ago for a non-corrosive spindle we used 32 per cent nickel steel, and for the valve seats a 90 per cent nickel alloy. I believe this was the American specification at that time for a high-superheat valve. At present some makers use $7\frac{1}{2}$ per cent nickel steel spindles and seating of copper alloy containing very little nickel, and it is an open question as to the life and behaviour of these under very high temperatures. Progress securing increased economy in the prime mover will still be made, particularly the possibility of reduced space arising out of the use of higher pressures; at the same time I think that from a financial aspect the boiler house at the moment offers greater scope in regard both to design as well as to operation.

**Mr. P. M. Baker:** The case put forward by the author in favour of high pressure and high temperature of steam scarcely seems to me to be very convincing. If we were able to neglect all considerations except those of elementary thermo-dynamics it could be readily demonstrated by simple inspection of the temperature-entropy diagram that (1) the efficiency of a steam engine increases as the maximum steam temperature is raised, and (2) the highest efficiency for any good maximum temperature is obtained with saturated steam—conclusions which have to be considerably modified when the very practical effects of wetness of steam and other considerations are taken into account. These modifications, at the extremes suggested by the author, can scarcely be allowed for otherwise than by extrapolation, from figures obtained from plant working under known conditions, and extrapolation is a somewhat dangerous expedient. From experience of some years in India with steam plant working at moderate pressure and superheat, I should be very chary of advocating extremes in the direction of either pressure or temperature, especially in view of the fact that: (1) Such plant would require unremitting care and observation, especially in the quality and quantity of feed—a difficult operation in a land where things are not what they seem—where, for instance, lubricating oil bought in the bazaar may quite possibly be de-odorized and coloured coconut oil masquerading as the very best mineral oil. These difficulties may not apply in an English station, but I fear that even here the plant would be the source of much worry. (2) The author has not, apparently, been in a position to show what increase in capital expenditure would be necessary. It would certainly be very high; and this, combined with the high rate of depreciation on boiler plant made of materials which are at present available, would, I should expect, absorb all the advantage which the author has set forth. For these reasons I feel that the only conclusion to be drawn from the paper is that the direction indicated by the author is probably the correct one, but that our progress along it should be by easy steps.

**Professor D. Robertson** (*communicated*): The idea that the latent heat of steam given out in the condenser causes a greater loss than would be obtained in a gas engine was at one time quite common, but a very elementary knowledge of thermo-dynamics shows it to be a fallacy. It is well known that the greater thermal efficiency of a gas engine is in reality due to the greater temperature range which it employs. With the same temperature range a perfect gas engine and a perfect steam engine would both reject the same amount of heat for equal amounts of mechanical work. The real effect of the latent heat of the steam is to enable a very much smaller mass of steam than of gas to deal with this heat. In itself, this would make a steam engine very much smaller than a gas engine of the same power and the same speed; but much of this advantage is lost by the additional fact that the pressure of the steam at the lower temperature is very low and its volume consequently very great. Thus, the ideal working fluid for a heat engine is not, as the author implies, a permanent gas in which there is no question of latent heat, but a fluid which is liquid at the lower temperature and has a very great latent heat. But there is another desideratum; the saturated vapour pressure should be moderate at the highest temperature which it is practical to use in an engine. It is here that steam is defective; with it, the upper limit of boiler temperature is set by the pressure obtained, and the maximum possible efficiency is thereby reduced. Superheating improves the efficiency, but does not raise it to anything like that corresponding to the temperature of superheat, because only a comparatively small proportion of the heat is taken in at that temperature. The bulk of the heat is taken in at the lower temperature of the boiler. The design of a steam turbine is complicated by the high velocity of the issuing steam consequent upon its low density. By employing a vapour which has a higher density and a lower pressure at high temperatures, a much simpler turbine can be used owing to the comparatively low velocity of efflux. Mercury fulfils these conditions. Attention may be drawn to an article by W. L. R. Emmet in the *General Electric Review* for January and February 1914 (vol. 17, pp. 47 and 99) on "Power from Mercury Vapour." This gives an account of a fair-sized experimental plant constructed at Schenectady in which mercury vapour at high temperature is employed to drive a simple turbine. In the cooling side of the mercury condenser, low-pressure steam is generated and used in a low-pressure steam turbine. In this way a great temperature range is utilized with only simple turbines, and a high efficiency is obtained. The only real difficulty seems to be that caused by the risk of escape of poisonous mercury fumes, and it is stated that this has been satisfactorily overcome.

**Mr. J. H. Shaw** (*in reply*): In answer to Mr. Ellis I would say that the paper could never have been written if a number of assumptions had not been made. Turbines of the size under consideration had not been built for the pressures and temperatures dealt with at the time the paper was written. Further, the ratio efficiencies assumed are not much better than those already obtained with lower pressures, and I see no reason why the steam consumptions given in the paper should not be attained in practice. Mr. Ellis gives an instance of a steam chest breaking after running for two or three years with steam at a tempe-

rature of 550° F. It has been an unfortunate fact that a few manufacturers have insisted on using cast iron and semi-steel, which is a mixture of cast iron and Bessemer scrap ends, after it had been proved most conclusively that cast iron was unsuitable for steam above 400° or 450° F., and I believe that up to 1914 the German manufacturers were even then using "Stahleisn," which was a mixture as above mentioned, and were insisting that it was suitable for steam up to 600° F. I fail to see how any boiler can evaporate 10 to 12 lb. of steam per lb. of coal, as with a heat content of the coal of 10,000 therms per lb. and steam containing, say, 1,300 therms the efficiency would be above 100 per cent.

I regret that I cannot agree with Mr. Sayers in his advocacy of the Diesel engine. Engineers are not in business for the purpose of achieving high thermal efficiencies, but for obtaining the best results at the least cost, and I maintain that the repair charges together with interest on the increased cost of Diesel engines over turbines and boilers would more than nullify any saving in fuel consumption when compared with a modern steam plant.

Major Taylor has to a certain extent misread the paper, as I did not set out to make out a case for extra-high-pressure steam. I must plead guilty to being somewhat prejudiced to the use of high pressures and high temperatures in a large power station running at good load factors, but I have not allowed this feeling to influence the paper to any extent. The idea was to draw up a correct balance sheet of the advantages and disadvantages. I do not, however, see why an increase of 2½ per cent in depreciation should be allowed on extra-high-pressure plant, particularly as the greater part of the station will not be affected by the increased pressure or temperatures.

Mr. Williams' suggestion of using oil and tar has been looked into in many parts of the country, but at any price that has been quoted me up to the present neither tar nor oil can compete with coal.

I cannot agree with Mr. P. F. Allan that the maintenance charges of a station using high-pressure steam are likely to be much greater than those of a station using, say, steam at 200 lb. pressure. As pointed out above in my reply to Major Taylor, many parts of the station are unaffected, and if a careful analysis is taken of the annual repair costs of power stations it will be found that the maintenance of stokers, brickwork, pumps, cooling towers, condensers, etc., forms a very large portion of the total repair costs. I do not think that any comparison can be drawn between land and shore practice, as a higher pressure without an increase in the temperature can be more easily taken care of than an increase in both directions.

Mr. Leevers' doubts as to the reliability of modern valves can be dispelled. A few years ago many manufacturers apparently thought that 32 per cent nickel-steel mixture was a chemical composition, instead of which it was a mere mechanical mixture, and the nickel was not uniformly distributed over the alloy; thus the behaviour of this alloy was most erratic and unreliable.

## North Midland Centre, at Leeds, 9 April and 14 May, 1918.

**Mr. R. C. Atkinson:** Even at a gauge pressure of 200 lb. per square inch the size of steam pipes required when units of 15,000 kw. capacity and upwards are installed becomes alarming, and though for this pressure they and the valves and fittings will be thinner than for 350 lb. I think there will not be found in practice to be much, if any, difference in the cost of pipes, valves, lagging, pipe supports, etc. It appears to me that the principal difference in cost between plant for 200 or 250 lb. and 350 to 375 lb. will be in the boilers, superheaters, and feed pumps. The difference in cost of the turbines should be very small, seeing that it is only the control valves, nozzle chest, and first stage or two which will be appreciably different. The question of feed water is vital. I note that the author refers to "lime soda" water-softeners for treating the make-up feed, but I think that for the large stations of the future the only method which will give really satisfactory results is to use evaporators, heated possibly with exhaust steam from auxiliaries and some live steam, and discharge the vapour into one of the following:—(1) main condensers, (2) condensers of the auxiliary generating plant, (3) separate condensers through which part of the circulating water from the main units or auxiliary condenser would be passed, or (4) to discharge it into the hotwells direct. Softeners of the "lime soda" type can never give the result required. Generally the quality and composition of the raw water varies and the softener is adjusted from periodic tests, so that if the composition of the raw water varies soon after the softener has been adjusted it will not be working correctly for the rest of the period up to the next test, resulting in improperly or insufficiently treated water being fed to the boilers, thus causing deposits in them with probably serious results at the temperatures obtaining at pressures of 350 to 375 lb. An interesting paper in connection with softeners was read before the Institution of Mechanical Engineers some 15 years ago by Mr. Stromeyher. Regarding the boilers and superheaters, the circular form for all parts is obviously the best, and rectangular sections or flat surfaces are not only inherently weak but generally involve considerable work being done upon the steel during the formation of the section. Recent researches on the part of metallurgists have emphasized the fact that steel is not the simple metal engineers have in the past been used to consider it, but a highly complex compound of various substances which is peculiarly susceptible as regards its physical properties to the temperature at which it is heated and worked, and to the method or means by which it is cooled after being heated. All steel which is to be used for vital parts should be most carefully treated when being worked in the sense of predetermination and control and recording of the temperatures at which it is heated and worked, and the manner and duration of cooling.

Practically all the leading makers of water-tube boilers in this country still trust largely to the human eye in these matters, and it is to be hoped that they will soon realize that this method which is a relic of by-gone times is now out of date, and unsuitable for use in connection with the construction of the high-pressure boiler of the future, which must be carried out on more exact and scientific terms. When one considers the care expended on torpedoes and shells during manufacture, the backwardness of the boiler makers in regard to the methods of manufacture they are using and proposing to use for these high-pressure boilers is rather disquieting, and I think it is high time they overhauled their works practice. The author apparently favours a pressure of about 350 lb. and I am in agreement with him. Regarding total temperature, I think a working temperature of 700° F., which will mean a range in practice from about 650° to 750° F., is as far as it is advisable to go at present until we have more experience of the wearing effect of high-temperature steam on metals and, particularly, turbine blades. In conclusion I should like to call attention to the articles in *Power* (vol. 47, no. 1) of January 1918, and in the *Electrical World* of 19th January, 1918 (vol. 71).

**Mr. W. M. Selvey**: The author comments on the low thermodynamic efficiency of the present cycle used for the generation of power. He points out that this is partly due to the working fluid, and suggests the alternative of other known working fluids and, finally, a perfect gas. It is a curious fact that all heat engines whatever their working fluid, with the exception of the Diesel engine which is a little higher, tend to realize a practical efficiency of about 30 per cent. With water as a working fluid a large size of unit is necessary and it must be operated at the highest possible pressure and temperature to realize this efficiency, while with engines using air as a working fluid the small units are almost as efficient as large ones. The margin of efficiency between what is now called a small steam unit and one of the largest size is, however, becoming very small. Recent tests of turbines of 3,000 to 4,000 kw. running at 2,400 and 3,000 r.p.m. have shown efficiencies within 5 per cent of the most efficient turbine ever made (Parsons 25,000 kw. set at Chicago), and the tendency of the largest size units being erected and designed in America is to decrease in efficiency for commercial reasons well-known to turbine designers. The steam turbine unit is nearing an efficiency beyond which very considerable increase in cost of construction and stresses in material have to be faced. The volume of business concerned is now, however, so large that it is not surprising that engineers are looking for even a few per cent improvement; and having exploited "superheat" and "vacuum" nearly to their utmost limits, we have only in this paper to consider the increase in pressure at a given total temperature. Increase in pressure with constant superheat gives a considerable gain, but increase of pressure with a constant total temperature, i.e. with a decreasing superheat as the pressure rises, is all that can really be counted on. This again is relatively small, being about 7 per cent in going from 200 lb. absolute to 350 lb. absolute, and about 11 per cent in going from 200 lb. absolute to 500 lb. absolute. These increases, which every engineer will expect to have discounted to some extent by reductions in plant efficiency, are not such as to give rise to any great enthusiasm for radical departures in engineering practice. To express these percentages in money, as the author has done in Schedule 1, rather obscures the issue. We really all think in percentages. The question which is most before the public at present is what price they will have to pay for their "cheap power" in the future, although other interests would have us confine our attention merely to the amount of coal burned to give them that "cheap power." With a possible consumption of 2 lb. of coal per unit with coal at 18s. 8d. per ton (10 lb. coal = 1d.) the coal costs of this power will be 0·2d. per unit. Ten per cent saving on this is 2 100ths of a penny. I venture to state that the saving of 2 100ths of a penny per unit on a selling price which is to-day between, say, a halfpenny at the lowest and a penny at the highest (in bulk) will not appreciably affect the future of "cheap power." Therefore I draw the conclusion that it is not advisable generally to increase the pressure and temperature used for power generation until sufficient experience has been gained to prove that the discounts on this 7 to 11 per cent are not too large to make it not worth while doing. There are some reasons why an increase in pressure is helpful quite apart from any increase in efficiency, and these are sufficient in themselves to encourage a gradual increase in pressure. There is one important aspect in which a high pressure renders increased efficiency possible, and that is in the direction of interheating. The initial impulse to the consideration of what interheating can do is due to Dr. Ferranti, and I had the pleasure some years back of going very thoroughly into the question with him. Complications which ensue from interheating steam at atmospheric pressure are considerable, but if the steam is initially at a sufficiently high pressure so that a fair amount of work can be got out of it by its expansion to a pressure well above the atmosphere, then the expanded volume is not too great to be dealt with satisfactorily. This, to my mind, is the principal justification for a really high pressure. In the meantime it is of great interest to engineers to consider the practical difficulties which will arise from increasing the pressure to, say, 350 lb. or 400 lb. and the total temperature to, say, 700° F. The turbine design offers no particular difficulties, although I cannot agree with the author's suggestion of almost equally high efficiency for the high pressures. The diaphragm gland losses will be very considerable in the impulse type of turbine, and the first blades will again become very small in the Parsons type of turbine unless gearing is adopted, which means gears of a very large size at a high speed. I should estimate the reduction in efficiency to be as much as 3 per cent. The question of the valves may prove somewhat troublesome. The steam pipes should give no trouble at all. The boilers should give no trouble from a stress point of view, but one does not feel so confident from a chemical point of view, and in my opinion the advance in pressure should be accompanied by very special water treatment aimed at producing a feed almost free from gases and

salts. Up to 250 or 300 lb. pressure we may still be able to get a cast-iron type of economizer, but above 300 lb. only the steel economizer is advisable, and much of the feed water as it exists to-day would be very doubtful material to pump into a steel economizer under 350 lb. pressure. I cannot help feeling that while nothing should be suggested to hinder the development of existing power-plant efficiency, engineers must really whole-heartedly turn their attention to the question of the 70 per cent of the total heat which, as I mentioned, is rejected by almost every form of heat engine. I have dealt with this in my little pamphlet on "Combined Hot Water and Electric Power Stations" which has appeared in the technical Press, and I refer to it again because I am more and more realizing that underlying the idea there is something fundamental which has not yet been grasped by engineers. It will be necessary to consider the means of mankind for all purposes, and every rigid doctrinaire cry such as "Electricity for all purposes" must inevitably fail in the light of human experience. No solution of the problem of the best utilization of our coal can ever be arrived at by providing for some needs of mankind and ignoring others. The electrical engineer is expanding his sphere of influence very much beyond that of electricity, and the time is coming when no engineer will be worthy of the name who confines his sympathies in a watertight compartment centred around his own immediate interests.

**Mr. J. Cauthery:** In the 1917 edition of a well-known pocket book for mechanical engineers I find the statement: "It is doubtful if pressure much above 150 lb. gauge will become common in view of the greater expense of high-pressure plant." This leads me to say that even qualified prediction on the side of doubt is very dangerous. Pressures well beyond 150 lb. have already justified themselves. It may be, as Mr. Selvey says, that super-pressure boilers will not become common everywhere, or will not become desirable in every kind of plant. With super-pressures and temperatures—by which I mean pressures between 275 lb. and 500 lb., and temperatures up to 700° F.—there will of course be considerably increased cost in power plant. It is just on that question of the corresponding saving that we have the relation of these two that will finally decide the matter. Now I think we have no figures as to cost given us in the paper, and no actual results in the few plants already at work at super-pressures and super-temperatures. That was not to be expected at this early stage. So far as I know, the only two super-pressure and temperature plants to be found in this country at present at work are the two mentioned by the author. This week I have had the opportunity of seeing the one at Rugby at the British Thomson-Houston Works. There we have an 18,000-lb. evaporation boiler at 350 lb. pressure and a superheat of about 200 degrees F., and a 1,500-kw. turbine. The other plant referred to by the author is at Carville and is a much larger plant. The boilers are worked at 275 lb. pressure. I am not sure of the superheat. I think it is about 200 degrees, and Parsons turbines are used. I do not know any of the results attained, but there is good reason for inferring that the Company are well satisfied with their experiments in this direction. The boilers in each case are of the marine Babcock type. As a set-off to the undoubted extra cost with these high-pressure plants, we have the smaller area they occupy, the greater power in a smaller space, and the relatively greater work that turbines and boilers will do compared with turbines and boilers for lower pressures and temperatures. Those points will have to be set off in the costs. The author has pointed out that we are going up to 475 lb. pressure and to a maximum superheat temperature of 700° F. The British engineer has been condemned in the non-technical Press for his conservatism, but I think the above development ought to satisfy the critics. The experiment of super-pressures raises a whole group of points. Most of the items might well form a theme in themselves. There are three groups of questions, viz. those arising out of the generation of the steam, those arising out of the transmission in the steam-pipe ranges, and those relating to the utilization of steam at the turbine end, with which Mr. Selvey has dealt. Now under the first of these, namely, generation, we have groups of questions relating to design, to safety, to deterioration, to repair, to feed water, to fittings, to the mode of firing, to the rate of firing, to water feeding, and to economizer versus reheater superheater; and it will be seen that each one of these in itself would provide an evening's discussion. As to design, we can go up to 500 lb. without any radical change of design in water-tube boilers. We have thicker drums and thicker tubes. We do not require anything thicker in the drums than what exists in marine practice, which goes up to a thickness of $1\frac{1}{2}$ inches or more. As regards the drums and the tubes, by reducing the diameters we can keep well within sound thicknesses from both an engineering and working standard. In the case of 475 lb. in which I am professionally interested, the main tubes are 3 3/16 inches diameter externally and the small tubes are 1 13/16 inches diameter, and the main tubes are in the region of $\frac{1}{4}$ inch. That thickness will, I think, work quite satisfactorily. I do not think there will be any practical difference in the heat transmission of the thicker tube from the point of economy as between that and the thinner tube. As to safety, that is purely a matter of sound construction and proper working. For the first—sound construction—we must look to the boiler-makers to give us a construction that approximates to machine construction; and it is certainly necessary that strict and competent supervision should go with the boiler from the plates at the plate-makers right through to the last stage until it is duly installed at the works. Then beyond temperatures of, say, 400° F. gunmetal is unsuitable for fittings. Steel or special metals are required. The question of safe working is also involved, and the question of feed water referred to by Mr. Selvey. I entirely agree with him in his remarks. For our make-up, we want a water as nearly as possible free from corrosive scale-forming properties. Unfortunately, as the author has pointed out, the softer and the better the water, often the more liable is it to cause corrosion. Because of this the make-up water question will need to be very carefully considered and thoroughly dealt with. If we can arrive

at satisfactory results in those respects we shall, as every plant engineer knows, remove a host of troubles and maintain boilers in good condition with, as the result, long life and small cost in repairs. How happy would most engineers be to feel that they could go on from year to year and never have to replace a tube. Having got that, there is the elimination of grease. It is an error to suppose that because we use condensate from turbines we shall necessarily have no grease. It is found that oil will creep along the turbine shafts and get into the water that way. That is a very important point, especially now that we are reaching temperatures where steel begins to soften. At 475 lb. pressure the temperature is 460° F. At 550° F. or thereabouts steel begins to soften. It will be seen therefore how important are cleanliness and freedom from grease. Bearing on that too, the rate of firing comes in. If we transmit heat to tubes at too great a rate through a given area of tube by pushing a boiler, we shall increase the temperature. I think both sound and safe working and also economy are to be found in designing our super-pressure boilers to work at an average rate of about 25 lb. per square foot. The best economy is found in the region between 20 lb. and 25 lb. There is room yet for better stokers and stokers that can be controlled for various stages of working. Whether we get the perfect mechanical stoker or not we can probably improve on what we do now. There is also the question of draught. The fashion of the hour is forced draught. I am not converted to forced draught as the soundest economy. In the case of super-pressure boilers and temperatures such as we have it does not appear to be necessary. If we limit the rate of firing and the super-pressure boilers to what is reasonable, with a good chimney we can get a draught to burn fairly good coal up to 40 lb. per square foot. That is as much as we ought to require from a boiler. Now the chimney costs very little expense in upkeep. It deteriorates but slowly, and it absorbs no power. That cannot be said of forced-draught installations. I shall be told we cannot burn with chimneys inferior grades of fuel such as we can with an adjustable forced draught. I admit that, but I doubt if we can get the best efficiency out of low grades of fuel with the use of super-pressure and temperature. Low-grade fuels have a great deal of soot and waste, and they reduce the efficiency of heating surfaces rapidly. We could have a very interesting debate on the subject of natural draught versus forced draught. In conclusion, I will refer to the subject of reheaters and economizers. As to the point raised by Mr. Selvey, that if we reduce the steam at the turbine down to atmospheric pressure before we take it back to the reheater we shall need very large steam pipes, I would suggest to him it is not needful to wait until the steam is down to atmospheric pressure. Suppose, instead, that we take it back at a pressure equivalent to about 300° F., and then take it to the turbine for its final and exhaust stage. It may be that considerable economy can be gained by a reheater. Re-superheating the steam for the final stage in the turbine may also have the effect of reducing the wear and tear of the turbine blades at that end of the turbine. It may therefore be found more profitable to put a reheater superheater in the place where an economizer would otherwise go. There is room for experiment; and the proof lies that way.

**Mr. J. Shepherd:** I propose to confine my remarks to the question of high superheat and steam pipes. It is of course generally known that the higher the superheat the greater the steam economy of steam generators, and especially so of turbines. Such steam must, however, be contained in pipes, valves, steam chests, nozzle boxes, etc., and the effect of steam upon the metals of which these are made is a vital matter. The limiting temperature for cast iron is soon reached at about 500° to 550° F. for permanent work. At such temperatures the graphite begins to separate out and cracks form in the body of the metal. For temperatures over 550° F. the only suitable commercial metal to use is steel, and with that metal there are the difficulties of welds in the pipes and their flanges. It is therefore somewhat surprising to find the author directly or indirectly recommending longitudinal pipe welds and welded-on flanges. I consider that for permanent work and high superheat all welds should be avoided both in the boilers, pipework and elsewhere. I am aware that pipe-makers have introduced acetylene welding very largely into the manufacture of high-pressure steam pipes and even attach large tee pieces to main pipes solely by acetylene welding after the fashion of a plumber's wiped joint. I do not consider such attachment to be nearly as reliable as a tee piece fixed by rivets in a workmanlike boiler-maker's job. The opinion I hold about welded-on flanges is based upon practical experience, as in a station with which I was connected very considerable trouble was experienced with pipe flanges subjected to a total temperature not exceeding 550° F. Within 6 years of continuous working, failures of welds occurred on 133 flanges on 12-in. pipes, 136 flanges on 8-in. pipes 140 flanges on 7-in. pipes, and 4 flanges on 4-in. pipes, which represented over 95 per cent of the total flanges in the station. Those welds were all coke-fire welds, and whilst arc welding or acetylene welding may be more reliable, I consider that such welds have not yet had sufficient time to establish a reputation for reliable permanent work. With high steam temperatures the question of pipe expansion becomes serious and requires careful design in the lay-out of the pipe work. Long pipe mains must be divided into comparatively short sections, the ends of the sections being solidly anchored to the steel work of the building structure, and elastic expansions inserted in the middle of each section; and the author has pointed out the best manner in which this can be done with a compound system of small expansion pipes. With expansions of considerable extent a form of telescopic joint would be extremely useful, provided it were possible to design a type of stuffing box and packing which could be made permanently tight and flexible with high-pressure high-temperature steam. The question of heat losses becomes more serious with higher temperatures. Such losses may be roughly expressed by the following equation

$$L = A\,T + B\,T^{1\cdot23} + C\,T^{4}$$

where A, B, and C are constants and T is the temperature. The first term represents the heat conveyed away by conduction at the anchors and supports, the second term represents the heat lost by convection or transfer by air currents. The last term expresses the losses due to direct radiation, and may be 60 per cent of the total loss. The aggregate losses for 1,000 ft. run of 12-in. uncovered pipe with 700° F. steam working continuously is 2,500 tons of coal per annum. With a good quality of pipe covering, 2 in. or 2½ in. thick, this loss could be reduced to one-tenth, and to a lower figure still if the increased cost of the covering allowed. As all pipe coverings depend largely upon the air cells within their media, it is important to see that the coverings are not sodden with condensed steam from leaky joints, and this again is a question of proper design and an efficient flexible system of piping.

**Mr. A. Q. Carnegie:** In the early days of condensing turbines, the exhaust end was extremely wasteful, although it was at the same time the most efficient portion of the turbine. This wastefulness was due to insufficient area in the exhaust blading, and to the size and shape of the exhaust outlet passages. These faults have been gradually eliminated, until now the velocity throw-away losses, and the friction and eddy losses in the exhaust passages in well-designed turbines are extremely small. It is interesting to note that the same faults were present in the design of high-speed petrol engines; for, until quite recently, the gas ports and valves were much too small, and large cylinders had to be fitted in order to obtain the power required. In the last year or two previous to the war, larger valves and passages were adopted, and thus enabled much smaller cylinders to be used. It is probable that if the petrol-engine designer had been through the mill of turbine experience, he would have realized the importance of inlet and exhaust area much sooner than he did. It is, of course, quite obvious on theoretical grounds that high initial temperatures are advantageous to steam turbines. Only the mechanical difficulties stand in the way of a commercial internal-combustion turbine. Unfortunately, these mechanical difficulties are very great, and for the present we may, I think, leave this problem to posterity, who will perhaps have different materials at their disposal. The use of the temperatures and pressures discussed by the author presents no difficulties other than choosing the best compromise of design in the turbines and boilers. I propose to leave boiler difficulties to be dealt with by someone having much more experience with them than I have, but I should like to suggest that it would be very interesting to hear whether the boiler makers have developed any design, or carried out any experiments with superheaters for temperatures much higher than those mentioned in the paper. I have in mind steam temperatures of the order of, say, 1,000 or 1,200° F. It would be interesting to hear whether at these very high temperatures any serious oxidation occurs in the superheater tubes (either inside or out), or whether the first layer of oxide protects the tube from further deterioration. If oxidation persists in the superheater at these temperatures, similar difficulties will probably be encountered in the turbines which will have to utilize the steam. In any case it is up to the boiler maker to solve the very high steam-temperature problem, because if he gets over the difficulties, there is little doubt that suitable turbines can be developed to utilize the steam. The author shows very clearly that with a given upper limit of temperature there is a considerable advantage in going to high steam pressures, and if—on the top of the 500 lb. which he mentions—higher steam temperatures can be utilized successfully, still further gains in efficiency will be obtained, owing to the decreased wetness and consequently reduced internal friction in the turbine blading. The question of very high temperatures is rather beyond the scope of the present discussion, but I make no apology for raising it, owing to the importance of the saving which may be effected. Coming back to the two main conditions discussed by the author, namely, a constant initial temperature of about 700° F., and the use of either low pressure with high superheat, or high pressure with moderate superheat, the advantage is shown to lie well on the side of the latter condition. Let us consider what higher pressures mean from a practical point of view in turbine design. For the same initial temperature, the steam will reach the saturation point and become wet in quality at an earlier stage in the length of the turbine. The specific volume of the steam will be smaller, and there will be greater percentage leakage losses in reaction turbines, due to the shorter blades, and in impulse turbines there will be greater disc friction-losses, so that both types are to some extent liable to a decrease in efficiency ratio with high steam pressures. The impulse type will be the more liable to suffer mechanically from the use of high-pressure steam because, owing to its steam velocity being so much greater than in the reaction type—somewhere about six times—a greater proportion of its blading will be liable to cutting by erosion, owing to the wetness point being reached more early in the expansion. With clean steam, blade erosion—except to a very moderate extent at the exhaust end—is practically non-existent in reaction turbines. The net blade efficiency is much greater in reaction turbines than in impulse—the top figures at the best velocity ratio in each case being 93 per cent and 87 per cent respectively. These net blade efficiencies are, of course, never attained in practice, the main losses in reaction turbines taking the form of clearance leakage, while in impulse turbines they take the form of disc friction, blade windage, and diaphragm leakage. In order to reduce leakage losses over the tips of the blades, reaction turbines are now almost invariably fitted with what is known as "end tightening" blading. In this class of blading the blade tips are provided with a projecting shroud, which runs close to a projecting barrier formed by the roots of the corresponding cylinder or spindle blades. The turbine shaft is arranged so as to be capable of delicate adjustment endways, so that its axial clearance can easily be set to the desired limit. As the whole of the clearance which controls the leakage is arranged axially, it follows that with this type of blading the radial clearance over the tip of [illegible] may be made as large as desired, and in

practice this usually ranges from 3/16 inch to ¼ inch. Turbines fitted with this type of blading are therefore free to distort to a very considerable extent without any danger of contact occurring between the blading and the cylinder and spindle respectively. The author has not been able to put forward any figures as to the relative cost of low-pressure and high-pressure power stations, and the following figures will therefore be of interest. They are approximate estimates for the power plant of a station consisting of three 20,000-kw. units complete with boiler plant, but they do not include has been made to cover interest on capital, depreciation, and repairs to plant. Coal has been taken at 10s. per ton; and 15 per cent has been added to the steam and coal consumption to allow for working conditions and auxiliary power.

It will be observed that the steam consumptions have been taken on quite conservative lines, but that they bear practically the same ratio as between low pressure and high pressure, as given by the author in Schedule 2. The result of the comparison is not favourable to the higher pressure plant, but this is almost entirely

| | | | | |
|---|---|---|---|---|
| | | 215 lb. (abs.); 388° F. sat., 700° F. total temp. exhausting to 1·5 lb. (abs.) | | 490 lb. (abs.); 465° F. sat., 700° F. total temp. exhausting to 1·5 lb. (abs.) |
| *Capital Cost*— | | | | |
| Boiler plant (including one-third spare plant) .. .. | | £187,000 | | £235,000 |
| Turbines, alternators, and condensers .. .. .. .. | | 261,000 | | 266,000 |
| Total .. .. .. .. .. .. | | £448,000 | Difference £43,000 | £501,000 |
| Annual charges at 15 per cent .. .. .. .. .. | | £66,400 | | £75,300 |
| Amount of annual charges per kw.-hour generated, at 175 millions per annum .. .. .. .. .. | | 0·0912d. | | 0·1035d. |
| | Full Load | Running Conditions | Full Load | Running Conditions |
| Steam consumption per kw.-hour .. .. .. .. | 10·5 lb. | 12·08 lb. | 9·5 lb. | 10·9 lb. |
| Coal at 6 lb. per lb. evaporation .. .. .. .. | 1·75 lb. | 20·1 lb. | 1·58 lb. | 1·82 lb. |
| Coal cost per annum, 175 million units at 10s. per ton .. | | £78,500 | | £71,000 |
| Coal cost per unit .. .. .. .. .. .. | | 0·1077d. | | 0·0974d. |
| 175 millions per hour .. .. .. .. .. | | 0·0912d. | | 0·1035d. |
| *Total Costs*— | | | | |
| Capital charges .. .. .. .. .. .. .. | | 0·0912d. | | 0·1035d. |
| Coal at 10s. per ton .. .. .. .. .. .. | | 0·1077d. | | 0·0974d. |
| Total .. .. .. .. .. .. | | 0·1989d. | | 0·2009d. |

If instead of taking coal at 10s. per ton, a cost of 16s. is charged for it, the total costs will be altered as follows:—

| | | |
|---|---|---|
| Capital charges .. .. .. .. .. .. .. | 0·0912d. | 0·1035d. |
| Coal .. .. .. .. .. .. .. .. | 0·1725d. | 0·1560d. |
| Total .. .. .. .. .. .. | 0·2637d. | 0·2595d. |

the cost of buildings or switchboards, as these would not be materially affected. The cost of the boilers (with spares), superheaters, economizers, mechanical stokers, all iron cased, wrought steel uptakes, induced draught fans and motors delivering into four chimneys, access ladders and galleries, feed pumps, main steam, auxiliary steam, feed, blow-off and incidental piping required in boiler house, hotwells, conveying plant for coal handling, and suction ash-plant for dealing with the ashes, is included. The turbine plant comprises three 20,000-kw. turbo-alternators, each complete with condenser, air and circulating pumps. An estimate is also given for the interest on capital, and the cost of coal, based on an annual output of 175,000,000 kw.-hours, 50 per cent load factor, a peak load of 40,000 kw., two turbines running, and one spare. An allowance of 15 per cent due to the considerably greater cost of the steam-raising plant, and it is by no means improbable that the manufacturers of the boiler plant have safeguarded themselves to a considerable extent. The additional cost of the turbines themselves is quite small.

**Mr. W. B. Woodhouse:** There is one point in the paper which I think the author brings out very clearly, namely, that the practical limit to be considered is not a limit of pressure but a limit of temperature. We are limited by the materials we use and their behaviour under high temperatures. If a temperature limit be accepted, then the available heat is greatest when within this limit the ratio of initial to final pressure is made as great as possible; that is with no superheat in the steam. On the turbine side this is a disadvantage, because the steam is practically wet in all

stages of expansion and the efficiency of the turbine is less than would be the case if superheated steam were used; the difference in efficiency is a little uncertain, but there is no doubt that superheat is desirable, and so a compromise is necessary. Reheating, of course, may affect the matter. Whether the 5 or 6 per cent gain by reheating is worth obtaining is perhaps outside the scope of this paper, but obviously, as Mr. Cauthery pointed out, with a higher pressure one can reheat at a pressure which will permit of a reasonable size of steam pipes. I quite agree that in high-pressure boilers, in fact in all boilers, more attention must be paid to the purity of the feed water than has been the case in the past. It would be disastrous to attempt to work at high pressures unless the feed water is pure. The question of using economizers at these high pressures is interesting. I do not suppose anyone is enthusiastic about the use of cast-iron economizers at a pressure of 400 lb., and there are two alternatives; one is to use a steel economizer, the other to consider a two-pressure system, to heat the feed water at a lower pressure and then take it finally into the boilers. That I think is worth considering. In the author's tables I think the benefits of the higher pressures are well brought out, and it will be noted that the saving does not increase uniformly, but as the steam pressure is increased the saving does not increase so rapidly. If one considers the additional cost, the additional difficulties of working which may arise, and all the various considerations that the author has dealt with, one can find a good many reasons against adopting at once without further practical experience a very high pressure. I have had lately to consider the design of a new station in which this point arose. Broadly speaking, it seemed to me that a boiler pressure of 350 lb. was about as far as one could justify going if one regarded the whole matter from the commercial point of view.

**Mr. H. J. S. Mackay:** The problem is not really a boiler-maker's problem, because the question of efficiency does not enter into it. There is no difference in efficiency whether one uses 160 lb. or 500 lb. pressure. There is nothing difficult in the construction, as it only resolves itself into a question of thickness of plates and diameters of parts, the thickness of plates and diameters being of such a nature as can satisfactorily be dealt with in a modern boiler-making plant. As a matter of fact, we have constructed boilers for 500 lb. pressure, and in one plant four boilers have been operating at 350 lb. pressure for upwards of six years, and I understand that Messrs. Babcock and Wilcox have an order from an electric supply company for something like 10 boilers at 475 lb. working pressure. In my view it is at the turbine end where economies are to be derived from the use of a high working pressure, and it is the electrical and mechanical engineer's part of the problem to exact the greatest efficiency therefrom. A previous speaker raised one question as to the limits of superheat. As far as my experience goes, in this country the maximum temperature for which we have constructed superheaters has been 650° F., and we have not put down many plants at this temperature. We have supplied a great number of superheaters for Russia at 700° F. total temperature, but none of our staff in this country have seen these in operation, although the Russian staff have reported that the results have been quite satisfactory. As far as a higher temperature than 700° F. is concerned, only one case comes within my knowledge, but not within my own experience, and it may be of interest if I recall the information conveyed to me. In Australia, some six years ago, friends of ours installed two multi-tubular boilers to work at 60 lb. pressure, equipped with superheaters to give 900° F. total temperature. The life of the superheaters at this temperature was only something like three weeks to one month; sometimes, they only lasted a fortnight. The plant was installed for supplying steam at a very high temperature, the high temperature being required for depositing enamel on tin tobacco boxes. I was told by the engineer operating the plant that he could not get ordinary steel tubes to stand this high temperature but in an emergency, no steel tubes being available, he had to resort to some ordinary gas-piping, and with gas-piping he re-tubed a superheater, with satisfactory results. He was able to run the superheater for over three months instead of six weeks. There were two boilers and two superheaters. He kept in stock two spare superheaters with tubes constructed of wrought-iron gas-piping, and when a superheater began to fail he replaced the defective superheater with another one. It would therefore appear that 900° F. superheat is an unsatisfactory temperature at which to work with steel tubes. Approaching the whole question of high pressures, as an engineer I have tried to cross-examine myself and satisfactorily answer the following question: "If I were asked to advise a client who had half a million of money to spend on a power plant, could I truthfully answer that financially it pays to install a plant at super-pressure?" I have with me a set of figures which do not quite coincide, as far as the cost of boiler plant is concerned, with Mr. Carnegie's figures, but taking his figures we have a difference in cost of a plant, between low pressure and high pressure, of £43,000. Now that difference in cost of plant requires 7·06 per cent for interest and redemption spread over 15 years, the interest being 5 per cent, and 2·06 per cent being required for redemption of the capital outlay. The coal saving is given by Mr. Carnegie as £7,400. The interest and redemption on the increased capital expenditure of £43,000 amounts to £3,040, leaving a balance of £4,360 net saving to meet the increased cost of maintenance. As a matter of fact this figure is less that 1 per cent of the increased capital expenditure set out by Mr. Carnegie's figures I think his figures for the cost of the boiler plant are altogether too low. Therefore, if I were asked to advise a client with half a million of money to spend, can I ask him to spend £43,000 additional to gain a financial return of less that 1 per cent? I am afraid that the answer must be in the negative. With careful estimates before one, it seems to me that, while higher efficiencies can be obtained by super-pressures, yet the matter is entirely a financial one, and, taking into account the increased cost of the plant, it does not pay. Mr. Cauthery raises a point about reheaters being placed in the rear of the boiler instead of the place usually

occupied by the economizer. For superheating, this position is not satisfactory; on account of the low temperature of the gases an enormous increase in superheating surface is necessary to obtain a reasonable heat transfer. The Stirling Company of America designed some 15 years ago what they termed a superheater boiler, which consisted of two generating banks of tubes next to the fire, the third generating bank consisting of a superheater; but the cost of the superheater in this position being high, put the adoption of this design entirely out of court. In the usual Stirling design, the temperature of the gases entering the superheater is from 1,200° to 1,600° F., whereas in the rear bank of the boiler the temperature of the gases entering the superheater would vary from 800° to 500° F. It is obvious, therefore, that much more heating surface would be necessary. I understand that in connection with the application of high-pressure plants the intention is to bleed the turbines and to utilize the steam therefrom for heating feed water, economizers being dispensed with. This does not appear to be sound practice. It is surely advantageous to obtain the highest possible amount from the heating of feed water, due to the waste gases in a boiler plant. It has been demonstrated time and again that live-steam feed-heating presents no gain in economy, but the question of heating is apart altogether from the broader aspects of this paper.

**Professor G. F. Charnock:** From the scientific point of view, I need not say that so far as thermal efficiency is concerned it is well known that high pressure is a means of obtaining an increase. But as some of the speakers have said, the matter does not end there. After all, the problem is, will it pay? It may be granted that it is possible to produce boilers and turbines for high pressures, but although some of the previous speakers have made out that there would be very little increase in the cost of the turbines, I cannot help thinking that a boiler to carry such a pressure as 600 lb. per square inch is going to be much more expensive than one designed for 350 lb. It is going a long way from 350 lb. to 600 lb. as proposed by the author. One thing to which attention might be called is, that we know very little indeed about the strength and properties of materials at high temperatures, and in actual service I think we know even less. At a temperature of 1,000° F., which has been alluded to quite gleefully, I venture to say that we are altogether in the dark as to how material will behave under ordinary everyday working conditions. Before we venture into regions foreshadowed by plants working at 600 lb. per square inch pressure we ought to know a great deal more about the strength and properties of materials at very high temperatures. The action of comparatively high pressures on cast iron has been mentioned as a case in point. In the paper it is stated on some American authority that the elastic limit is seriously affected at such temperatures as it is proposed to employ. In face of such evidence it would be wise to hesitate, and at any rate some research should first be carried out, to qualify us to tackle these problems as light-heartedly as some of the speakers would venture to do. It might have been expected that most engineers, at first sight, would have been inclined to view the author's proposals with some little aversion. Certainly it is very generally believed that in adopting high pressures, say in the region of 600 lb. per square inch, many difficulties will have to be faced which do not arise at pressures of 200 to 300 lb., which latter are easy to deal with by comparison. The Diesel engine is an instance where fairly high pressure has been used, but experience has shown that high pressure has really not contributed to the success of the machine. The theoretical gain which is possible by increasing the pressure from 200 lb. per square inch to 600 lb. per square inch has been given at 10 or 11 per cent. From this must be deducted in the first place some provision for increased cost of boilers, plant, and probably turbines. Then there are going to be some inevitable losses to counterbalance to some extent the expected gain. A matter which has not been mentioned is the temperature of the water in the boiler. It will go up very considerably and the flue gases will apparently leave the chimney base at a very much higher temperature than is the case at present. Incidentally, the action of pure water, or nearly pure water, on metals at high temperature is another thing that will have to be looked into. The author proposes, in his ideal boiler, to employ gas-firing on the surface-combustion principle. That seems to foreshadow the use of a plant designed to utilize waste products, or by-products, more correctly speaking. Does not this suggest that, after all, instead of devoting so much time and labour in endeavouring to get a little bit more of the theoretical 10 per cent at the top end of the scale, it would be better to do something to avoid the monstrous loss of 60 per cent which occurs in the condenser and cooling tower? Personally, I think it is a matter which engineers will have to deal with. The previous speaker, I was pleased to note, put it forward in that way. Instead of regarding this enormous loss as irrecoverable it should be treated as a question of waste products. If engineers adopt the line in firing the boiler that every care is to be taken to get out the valuable by-products, it is only an extension of the same principle that every endeavour should be made to cut down the enormous loss alluded to. There is a far better chance, it seems to me, of securing some reasonable degree of economy by tackling that tremendous loss rather than by struggling against almost insurmountable difficulties, in the present state of our knowledge, to get a little bit of that 9 or 10 per cent at the top of the scale.

**Mr. J. M. Newton:** I wish to touch on one point, namely, the effect of high pressure and superheat on the efficiency of a turbine. One of the most valuable features of the paper are the elaborate tables giving the influence of various conditions of pressure and superheat. The results, of course, depend on the validity of the assumption on which they are based. The author goes very carefully into this question, and he ends by assuming for large units a thermodynamic efficiency ratio of 80 per cent, with steam at 200 lb. pressure, 150 degrees superheat, and vacuum 28½ inches, and that the same efficiency ratio can be obtained with pressures up to 350 lb. That is a very

good figure indeed, and I think it will probably be obtained in the near future from large units. At present I believe 77 per cent under those conditions to be about the best figure so far attained at the pressures usual to-day. Supposing, however, the 80 per cent efficiency is wrong, how will the results be affected? If the change is proportional throughout the range of conditions assumed, the percentage of saving will not be affected. The actual amount of the saving will be greater as the efficiency is lower? Another and independent question is how the efficiency varies with the steam temperature and pressure. I think we have in Mr. Baumann's data on the effect of superheat (on which the author relies) a fairly reliable guide. When it comes to the effect of pressure, opinions are much more divided. It will perhaps be within the recollection of many of us that recently in *Engineering* a discussion took place between representatives of two of the leading engineering firms in this country on the value of increase of pressure, one maintaining that increase of pressure led to a reduction of efficiency ratio. In this very difficult and complicated question perhaps the safest guide to follow is the law of similitude. It is well known that the total weight of steam passed per hour by a turbine is closely proportional to the absolute steam pressure measured on the turbine side of the governing valve. Consider a turbine taking steam at an initial pressure of, say, 150 lb. per square inch absolute and exhausting at 1 lb. per square inch absolute. Let the initial and exhaust pressures be doubled. Then approximately the total weight of steam passed per hour and the total amount of internal leakage are doubled; hence the percentage leakage loss is unaltered. At any point in the turbine the pressure is doubled and the specific volume halved; hence the total volume, the steam speed, and the hydraulic efficiency of each stage are the same. To make use of the energy which can be liberated by the steam in expanding from 2 lb. per square inch absolute to 1 lb. per square inch absolute (in order to make the exhaust pressure the same for both cases) a row or two of blades must be added at the exhaust end of the turbine when supplied with high-pressure steam. Thus by doubling the steam pressure and adding a row or two of blades at the exhaust end a turbine is obtained giving twice the output with the same efficiency. If this argument be safe, it shows two things. First (as the author assumes), given suitable design and size, the turbine can be made at high pressures to give very closely the same efficiency ratio as at ordinary working pressures. In the second place, that its cost need not be much higher, for in many designs the extra strength required at the high-pressure end can be obtained cheaply. In that respect the argument confirms the very interesting figures which have been put before the meeting by Mr. Carnegie, showing, as they do, that the extra cost of the turbine is not great, but the increased cost would lie in the boiler house.

**Mr. J. H. Shaw** *(in reply)*: I am in agreement with Mr. R. C. Atkinson regarding the difference in capital cost between plant for 200 lb. and plant for 350 lb. pressure. It is surprising, when making a list of articles comprising a modern power station, what a few of the essential parts are affected by the higher pressure. When taking into account the decrease in size of steam pipes, I am of the opinion that a piping range designed for the higher pressure should not cost any more than one designed for 200 lb. pressure.

Mr. Cauthery's contribution calls for little comment, it being practically a welcome addition to the data contained in the paper. His proposals to install the interheaters in the flue, in the place generally occupied by the economizer, will not be satisfactory unless the boilers are considerably over-run or the back temperatures are higher than is usual with present practice. If it is decided to reheat the steam at 90 lb. gauge pressure (i.e. 105 lb. absolute), the temperature will be 331° F., and it is at once evident that with gases at between 500° and 550° F. very little reheating can be done.

Many engineers have encountered the trouble experienced by Mr. Shepherd, of fire-welded flanges becoming loose on steam pipes. This trouble should have been prevented by efficient inspection in the makers' works. Modern welded flanges are to all intents and purposes an integral part of the pipe, and should give no more trouble than the longitudinal weld in the pipe itself.

## North-Western Centre, at Manchester, 26 November, 1918.

**Professor G. Stoney**: The slide that the author showed of a cast-iron valve which failed at the low temperature of 450° F. is most interesting, for it is generally considered that cast iron is free from growth at such a temperature. What really seems to happen when cast iron is exposed to high-temperature steam is that the steam gets in alongside the graphite plates and causes oxidization there, and consequent swelling and disintegration of the cast iron. This is hardly a metallurgist's description of what occurs, but is one that I think appeals to the ordinary engineer. I have known cast iron grow as much as 3 per cent in its dimensions, which will of course cause considerable distortion of a turbine casing, with consequent trouble. In some cases the material becomes quite brittle and almost like loaf sugar dipped in ink. Generally, it is considered that about 470° F. is a safe temperature for cast iron, but the author shows a case where growth occurred at 450° F. There has been little trouble with 100 degrees F. superheat, but a good deal with 150 degrees, which would give temperatures of about 470° F. and 520° F. It is noticeable what a small proportion of the heat of the coal can be turned into power. This is due to the Second Law of Thermodynamics, which can be stated as the law that heat cannot be transmitted from a cold body to a hot one. One way of stating this is to say that we cannot boil a kettle of water by putting it upon a lump of ice. This law is entirely a law of averages; and if we could get hold of the individual molecules it could be circumvented.

The late Clerk Maxwell conceived two chambers with a trapdoor between, worked by a being generally known as "Maxwell's demon." When a fast-moving molecule came along, he let it pass through the door one way; and when a slow-moving molecule came along, he let it pass the other way. Thus one chamber became hot and the other cold, without any expenditure of energy; and the difference of temperature could be used to work an engine. Unfortunately, no one has been able to get hold of Maxwell's demon. One way would be to use coal in a battery; but here again we do not know how to do it. Some day, however, we may learn how to get over the Second Law of Thermodynamics and then there are great possibilities. So far as our present knowledge goes, to increase the efficiency the temperature range must be increased; and the author has well shown the gains that can be obtained. Here I would ask that more attention be paid to lowering the lower limit of temperature, or, in other words, improving the vacuum. There should not be more than 20 degrees F. between the temperature of the cooling water and that of the vacuum; but there is often 30 degrees or more. I was rather surprised to see that in Schedule 1 the author takes the quantity of cooling water as only about 45 times the steam condensed. That means a difference between the inlet and outlet water of 21 degrees, or, allowing 6 degrees loss in the condenser, say 27 degrees between the temperature of the steam and the temperature of the cooling water. Except in unusual cases, where there is a large lift—as is sometimes the case in cooling towers—I should have thought that 65 to 70 times the steam condensed would be better, for the quantity of circulating water. It must be remembered that every 3 degrees saved in the temperature of the condenser means about 1 per cent of the steam consumption; and that 12 degrees saved would mean the difference between 365 lb. and 500 lb. steam pressure. It is most important to have clean condensers and efficient air extraction; and a large margin must be allowed for the possibility of air leaks. There are many forms of rotary pumps that give large air extraction, and there is also the steam jet. My own opinion is that without a steam jet it is impossible to get really efficient air extraction, and that sooner or later we shall have all condensers fitted with steam jets for the extraction of the air, followed up by some sort of air-extracting pump, which will abstract the vapour after it has been partially concentrated by a steam jet. The heat in the steam jet is not lost, for it is used to heat the feed. It is also most important to avoid air getting into the boiler: and the device that the author shows for separating the condensate, so that it does not come into contact with the air at all, is most interesting. Boiling at atmospheric pressure as a rule is not sufficient to take out all the air; a part of the air will still remain in, even after boiling; but if we boil water under a vacuum, practically all the air is probably extracted. I do not propose to deal with the effect of high pressures and temperatures on the boilers and pipes; but I should like to say a word or two about the effect upon turbines. In the early days a great many troubles were due to high temperature. When high superheats first began to come in, much trouble occurred, which was largely owing to insufficient provision for expansion and to the growth of cast iron. The growth of cast iron can be completely overcome by substituting for cast iron mild steel or a steel casting; and an interesting point mentioned by the author is that semi-steel is not safe. In semi-steel there is graphite, and wherever we have graphite there is sure to be trouble due to high temperature. These troubles can be got over by using a good design and suitable materials, but the price is high; I would strongly recommend that nobody should go in for cheap turbines with high pressure and temperature—it is only asking for trouble. A great deal of trouble with turbines has been caused by the almost universal practice of taking the lowest tender. The saying "cheap and nasty" is very true. It is true throughout everything. There are several manufacturers of turbines in this country who are thoroughly reliable. But if we cut them down to the last penny by competitive tender, we are perfectly sure to get a bad job. No firm can afford in the long run to do work that does not pay. I feel with the author that for these very high temperatures and pressures it will be wise to have two cylinders or tandem turbines. The range that he proposes, from 736° to 90° F.—i.e. 646 degrees F.—is a great deal to handle in one cylinder if the highest efficiency is also sought. I believe that the turbine of the future for very high temperature and for very high pressure will be a tandem or cross-compound one: it will have a small high-pressure cylinder in which the sting of the steam, the high temperature, is taken out. This high-pressure turbine will be made of steel castings and steel forgings This is also an advantage for the very big sizes, with high vacua and high speed, that we are coming to, since the low-pressure turbine can be double-ended without difficulty, and thereby the terminal losses reduced to one-quarter. Another way of doing it is Mr. Baumann's very ingenious arrangement of what might be called tandem blading; and I believe that this method has a future before it for big sizes with high speeds and high vacua. Even then, it may be found advisable in the future, in order to reduce terminal losses, to have the low-pressure turbine double ended, especially in cross-compound or tandem turbines. Another point is that the small high-pressure cylinder will have a higher efficiency than if it were the first part of a large turbine, and also that the parts are smaller and easily handled. In these large turbines one very soon comes up against the load gauge of railways, which limits to a very great extent the size of the parts that can be carried. In certain cases larger parts can be carried by road; but the size of turbines is so large now that very serious consideration has to be given to the carriage of the larger parts. The author mentions intermediate heating. I think it quite possible that this will come into use; but I would ask that the intermediate heating should not be too much, and that the temperature in the big low-pressure cylinder should be moderate in order to avoid expansion and other troubles. A point that will have to be very carefully considered is the effect on steels of temperatures of 700° to 800° F. There seems to be some evidence that a very consider-

able reduction in the ductility occurs at moderate temperatures, the ductility increasing again at higher temperatures. At high temperatures such as in the region of 1,400° F., the ductility of steel becomes something like that of lead: it is very high indeed. At moderate temperatures, however, say between 600° and 800° F., there is a certain amount of evidence that the ductility falls to a large extent, and this should be carefully considered. Practically nothing is known, so far as I can trace, about the effect of temperatures such as we are dealing with in these turbines upon the shock-resisting properties of steel. There is, however, a small amount of evidence that this goes down very much. I should like to mention also that the question of glands will have to be carefully considered. There has been a good deal of trouble with carbon glands when high temperature steam was used; and it is quite possible that if such glands are used some arrangement must be made to cool the steam that goes into them. On the whole, I think that high temperatures and pressures are quite practicable from the turbine-maker's point of view, provided—and this proviso should be carefully noted—that prices are not cut and that the best designs, materials, and workmanship are used. Schedule 2 in the paper shows that there is also a very substantial amount of capital available for these requirements.

**Mr. K. Baumann**: The author has referred to the use of other substances than steam and water in order to obtain better heat efficiencies. I am not of the opinion that great improvements can be obtained in that direction, and my impression is that we ought to be glad we have got such substances as steam and water. These have many advantages over such a mixture as air and gas, which is used in gas turbines. Steam can easily be condensed, doing away with bulky and inefficient compressors. Further, steam can be used very conveniently for feed-heating, and if properly applied the overall efficiency of a steam plant is considerably increased without greatly increasing the cost of the installation. I quite agree with the author that if we devote our attention to improving the steam prime mover, and leave the gas turbine alone, we shall get a better reward in the final result. With the steam prime mover efficiencies can be obtained approaching the efficiency of the Diesel engine. The author has referred to the utilization of a high vacuum, and Professor Stoney has emphasized the point. It is quite correct that for practically every 3 degrees F. by which the temperature is lowered in the condenser we save 1 per cent of the steam consumption; whereas an increase of 33 degrees F. is necessary at the upper temperature range of the cycle in order to get the same improvement. That shows the importance of obtaining the highest possible vacuum in the condenser. It is, however, no use having a high vacuum in the condenser unless we get that vacuum at the leaving edge of the last row of moving blades, because that is where the thermal energy has the last chance of being transformed into useful mechanical work. In order to obtain this, it is necessary to have an exhaust of large size and efficiently designed so as to get a stream-line flow of steam from the blades to the condenser. In addition, it is necessary to have a large leaving area. A small blade area results in large leaving losses, which again means energy thrown away unnecessarily. The author refers to turbine makers not being in accord as to the variation of the efficiency to be expected with varying pressures. It is a question of price. If a higher price is quoted, a better efficiency can be given, but if a cheap turbine is wanted the maker cannot afford to give an efficient turbine. Professor Stoney's remarks in that respect are quite correct. There is one point in the paper which requires further explanation. The author quite rightly takes as the basis of his calculation a constant efficiency independent of the steam pressure. A correction is of course required in accordance with standard practice to allow for variation in superheat. In Schedule 1 I notice that for 500 lb. steam pressure he takes a higher efficiency than for 365 lb. pressure. In the last column he takes an efficiency of 80·2 per cent for a superheat of 268 degrees F. In the third column from the end with 365 lb. pressure and practically the same superheat, 250 degrees F., he takes an efficiency of 78·9 per cent. There is thus a difference equivalent to 1·5 per cent in heat consumption which is not accounted for and which requires some explanation. For calculating small differences of the order dealt with in this paper, it is very risky to make the calculation all the way through without examining step by step the differences due to the various factors which have the principal influence upon the result. Unless we take this precaution we are liable to commit errors, which are difficult to detect otherwise. To appreciate fully the importance of the various factors affecting the result it is essential that these differences should be considered, and I regret that they have not been put down in separate columns in the paper. It is most interesting, for instance, to know how the improvement in the overall economy obtainable by raising the superheat from 200 degrees to 300 degrees F. is made up. By comparing in Schedule 1, columns 3 and 5 and columns 9 and 11 respectively, we get the differences shown at the top of page 98 in favour of the higher temperature expressed in per cent of consumption at lower temperature.

There is, therefore, a discrepancy to the extent of over 1 per cent in the author's figures. The correct decrease in heat consumption is 3 per cent for an increase in temperature of 100 degrees F. between 600° and 750° F. Actually the increase may be slightly higher owing to increase in boiler efficiency with larger superheater area. As far as temperature is concerned, therefore, I think it will be safe to say that the highest temperature which the material will safely stand should be adopted. I can assure members that a normal temperature of 700° F. with peaks up to 750° F. is quite safe, as far as the turbine is concerned. A turbine suitable for high temperature should be provided with nozzle boxes, even if a single Rateau wheel is used for the first stage. The temperature drop in this case is about 100 degrees F., and by the use of separate nozzle boxes the temperature to which the cylinder is subject is 650° F. instead of 750° F., which is a decided advantage. Schedule 2 gives information with regard to the improvement which can be obtained due to

| | | | | |
|---|---|---|---|---|
| Pressure | | | 215 lb. | 365 lb. per sq. in. abs. |
| Increase in superheat from | | | 200° F. to 300° F. | 200° F. to 300° F. |
| Difference in consumption | due to increase in heat drop | | 6·0 % | 5·95 % |
| | due to change in efficiency | Mr. Shaw | 1·25 % | 2·00 % |
| | | Speaker | 1·00 % | 1·00 % |
| Corresponding decrease in steam consumption | | Mr. Shaw | 7·25 % | 7·95 % |
| | | Speaker | 7·0 % | 6·95 % |
| Power for auxiliaries | | | 0·12 % | 0·15 % |
| Difference in overall steam consumption | | Mr. Shaw | 7·37 % | 8·1 % |
| | | Speaker | 7·12 % | 7·1 % |
| Difference in total heat in steam from temperature of hotwell | | | 4·1 % | 4·2 % |
| Corresponding difference in overall heat consumption | | Mr. Shaw | 3·27 % | 3·9 % |
| | | Speaker | 3·02 % | 2·9 % |
| Differences as shown by Mr. Shaw in coal consumption, last line but one | | | 4·4 % | 3·6 % |

higher pressures, the basis of the calculation being a constant temperature and a varying pressure. The pressure varies from 215 lb. to 500 lb. Here again it is very important to consider the differences.

thing above 400 lb.—a two-cylinder machine ought to be used Moreover, it is very desirable that cylinders which are subjected to very high pressures should be small in diameter. That means that we must use a

*Differences in Heat Consumptions given in per cent of Consumption at Smaller Pressures.*

| | 215 to 365 lb. per sq. in. abs. | 365 to 500 lb. per sq. in. abs. |
|---|---|---|
| Pressure increased from | | |
| Increase | 70 % | 37 % |
| Difference due to heat drop | 5·37 % | 2·97 % |
| Difference due to change in turbine efficiency owing to change in superheat | −0·63 % | −0·51 % |
| Due to difference in power required by auxiliaries | −0·10 % | −0·12 % |
| Due to decrease in total heat from temperature in hotwell | +0·60 % | +0·55 % |
| Total decrease in overall heat consumption due to higher pressure | 5·24 % | 2·89 % |
| Difference calculated from the author's figures for coal consumption | 3 % | 5·2 % |

There is a considerable error in the author's figures, which, to my mind, changes the aspect of the whole situation. It means that there is a good deal to be said for the adoption of 350 lb. per square inch gauge pressure, because we get a saving of over 5 per cent, whereas the saving between 365 and 500 lb. per square inch gauge is much smaller. It is very questionable whether with ordinary conditions it would pay to use 500 lb. per square inch. It may pay where the load factor is very high, such as in the case of a linked-up system where a power station can be kept at full power the whole time. The improvement which can be obtained by increasing the pressure can be expressed as follows:—

For every 10 per cent increase of pressure we get an improvement in overall economy of 1 per cent.

This is equivalent to an improvement of

4 per cent for 50 per cent increase in pressure.
7 ,, ,, 100 ,, ,, ,,

Those figures are sufficiently accurate for estimating purposes, and are confirmed by the corrected figures I have given just now. I agree with the author and Professor Stoney that for very high pressures—any-

high speed (r.p.m.) for the high-pressure cylinder. This can be obtained in a single-shaft arrangement using a low-pressure turbine designed for high speed, or by using a cross-compound arrangement. Personally, I think a single-shaft arrangement is much preferable, being simpler in many ways, especially as regards running. With regard to high pressures, there is one important thing to bear in mind. The higher the pressure the smaller the steam pipe, the better it is to build up flexible steam pipes, and the easier it is to allow for expansion. This advantage is considerable. With a 20,000-kw. turbine with 200 lb. pressure, we should require a 16-in. pipe, and for 500 lb. pressure only a 10-in. pipe. In conclusion, I should like to say again that as far as temperature is concerned 700° F. is quite feasible and turbine makers are willing to guarantee turbines for the maximum temperature of 750° F. As far as presssure is concerned, I think there is a good deal to be said for increasing the pressure to 350 lb. per square inch gauge. There is very little difficulty as far as turbines are concerned, and from what I gather there is very little alteration required as far as boilers are concerned.

**Mr. S. L. Pearce**: I think the point of view that will

be taken by most station engineers will be that at the present time there is no source open to them—by commercial and practicable means—of improving the economy of steam plant, other than by increasing the heat range. And with the prospect of, say, a 10 per cent theoretical gain by so doing it is naturally a subject to which they are bound to devote their best attention. We have heard from the two previous speakers, than whom—I think it will be agreed—no one in this country is more competent to speak, that from the point of view of the turbine builders there is no difficulty, provided we are prepared to pay the price, in building a turbine which at any rate will function perfectly satisfactorily at a working pressure of 350 lb. and a total temperature of 700°–750° F. That seems to be common ground. I think also we might say that with the experience which has been gained—notably at Rugby on the Babcock and Wilcox boiler—the standard water-tube boiler to-day can, with slight modification, be made to operate safely and satisfactorily at 350 or 375 lb. pressure. If it is desired to go above that pressure, up to the limit of some of the figures that have been mentioned to-night, very serious modifications would have to be introduced into the design of the boiler. A great deal of experimental and pioneer work remains to be done before we see pressures of 500–600 lb. adopted. But at a cost of, I understand, about 20 per cent increase the standard water-tube boiler to-day, working at 200–250 lb., can, with certain minor modifications and by the adoption of heavier sections, be manufactured for the highest pressure that I have indicated, viz. about 350–375 lb. I think from what we have heard to-night and what we may have gathered in other quarters it is very debatable whether—from the point of view of station efficiency and having regard to the extra capital costs and difficulties incidental to working pressures of 500–600 lb.—it pays to go beyond my figure. The author has already emphasized the point that up to the present we are really without very much experience on this matter. Reference has been made to the plant operating at Rugby. I do not think any figures have been published, but one is given to understand that the results are perfectly satisfactory. In this country there is a station under construction to which the author has referred; he has not named the station, but in the paper he has mentioned that Messrs. Babcock and Wilcox are at the present time building boilers for a 475 lb. pressure. I do not think it is any secret—it seems to be pretty common knowledge among engineers—that these boilers are destined for a new station on the Tees side, and presumably a working pressure of about 450 lb. is being adopted. The results obtained from that station when it is at work should be of enormous importance. In this country—excepting the Rugby boiler—there are no plants with a higher working pressure that 250 lb. The author has referred to certain plants in the United States. It should be noted that the highest pressure adopted is at the Detroit station plant of the Public Service Company in Northern Illinois, which operates at 350 lb. pressure and 225 degrees F. superheat. There is another plant, viz. that of the Buffalo General Electric Company, operating at 300 lb. and 275 degrees F. superheat. And I understand both those plants are working most satisfactorily. Personally, my own view is very much as summed up by Mr. Baumann, and it is on those lines that I am hoping to develop the new Manchester station at Barton, namely, to adopt a working pressure at the turbine of 350 lb. with a boiler pressure of 375 lb. and superheat approaching 300 degrees F. That seems to be within safe lines and, as I say, it is along those lines that I hope the Barton station will be developed. Incidentally I intend to use generating units of 25,000 kw. rating and very large capacity boilers. I think it will be agreed that thermodynamic considerations favour the use of high initial pressures rather than high superheats, but it will also be agreed no doubt that the economy will be greater if we keep up the superheat as well as the pressure. There are certain substantial reasons why the superheat should be kept up in proportion to the pressure. One reason is that as the pressure goes up the density of the steam increases and the frictional losses in the turbine become proportionately greater. Therefore it is necessary to counteract the greater density of the steam by increasing the superheat. Then again by increasing superheat we prevent the advancement of the dew point into the high-pressure stages of the turbine, with the consequent resulting loss which that entails. Reference has been made to the question of pipes and joints and expansion. I fully agree with the previous speakers that the use of higher pressures will entail the use of pipes of smaller diameter but more of them, i.e. there will be a greater subdivision of the pipe-work lay-out. The author has shown a slide which illustrates a system of jointing used at the Buffalo General Electric station by Mr. Sargeant of Chicago. In that system the welded steam joint is made inside the bolt circle—not to displace the bolts but to seal the joint. I believe that this method is likely to have a wide application. Another observation may be made on this question. I think it is quite pertinent to the point. The use of high-pressure superheats is more likely to be adopted in stations operating with high load factors, obviously on account of the expenditure of heat units required for heating up the complete apparatus. I want to say a word or two with regard to Schedule 1 in the paper. The author has explained exactly what those figures mean and how he has calculated them, and whilst I am not disposed seriously to criticize the relative results, I do think that they are probably understated especially for the pressures of 365 lb. absolute. I have prepared the following figures which appear to demonstrate the soundness of the case for using working pressures up to 350 lb. per square inch:—

*Pre-war Prices of Plant affected by High Pressures.*

| | £ per kw. |
|---|---|
| Turbine only .. .. .. .. | 1·20 |
| Boiler, economizer, and superheater .. | 2·34 |
| H.P. pipework .. .. .. .. | 0·35 |
| Feed pump .. .. .. .. | 0·11 |
| | £4·0 |

If we assume an overall 20 per cent price increase due to higher pressure, which is probably an outside figure, the above £4 becomes £4·8.

| | |
|---|---|
| Difference in cost on a 20,000-kw. plant .. | = £16,000 |
| Add an overall 60 per cent for war increases and the £16,000 becomes .. .. .. | £25,600 |

Correcting the author's figures in Schedule 2 :—

| | |
|---|---|
| For a 60 per cent load factor and coal at 15s. per ton, the saving per annum for a 20,000-kw. plant when working at 365 lb. pressure (abs.), as compared with 215 lb., equals .. .. .. .. .. | £3,150 |
| Capital that can be expended on one plant of 20,000 kw. for annual payments to absorb £3,150. Life of plant 15 years. Sinking fund accumulating at 3 per cent compound interest. Interest or dividend payable on capital at the rate of 5 per cent simple basis, equals .. .. .. | £30,361 |

We have had in the last few years some details of that very remarkable station of the Detroit Edison Company at Connors Creek, U.S.A. The conditions at Connors Creek may be compared with column 4 in Schedule 1, after making the necessary corrections for load factor, calorific value of the fuel used, and the boiler-house efficiency. The average weekly results for the Connors Creek plant are 1·42 lb. of coal per kilowatt-hour, as against the author's calculated figure of 1·82 lb. One naturally asks the question—How is it done? Probably the answer will be—"concentration of boiler plant in large and few units." Digressing for a moment, I think this is a most important line of development, and one that we ought not to overlook in designing our boiler houses of to-day, quite apart from the question of the pressures and superheats to be adopted. In the Connors Creek station they are using some very large boilers. Each of those boilers has 23,500 square feet of heating surface and they have no economizers. It seems to me that the employment of large boiler units is a direction in which the British engineer might well find a useful lead. Again I may state that in connection with the Barton station we are proposing to use boilers of large capacity, the heating surface of the boiler and the economizer together being practically the same figure as I have given for the Connors Creek boilers. The Barton boilers will be of such capacity that I estimate three of them will easily provide steam for a turbine of 25,000 kw. capacity I do feel that there should be no serious difficulty in adopting boilers of this size for the higher pressures and superheats that I have indicated, namely 350 lb. and 250–300 degrees F. The author then goes on to say that the natural development of the turbine for higher pressures appears to be in a line with the Parsons two-cylinder machine. I take it he has in mind there the question of pressures of 500 and 600 lb. and possibly very high speeds. It does seem to me—and I believe Professor Stoney and Mr. Baumann would be prepared to agree—that a turbine of 25,000 kw. capacity running at 1,200 or 1,500 r.p.m., and operating with a vacuum of 29·1 inches, could be built in one cylinder so long as the working pressure did not exceed 350 lb. No doubt the author had in mind the higher speeds, something of the order of 2,400 or 3,000 r.p.m., when writing that paragraph. I should be glad to hear what he has to say on that matter. On the other hand I would quite agree that high-speed machines lend themselves better to the adoption of very high working pressures, say of the order of 500 or 600 lb. It here becomes a question of balancing the extra capital cost involved in two-cylinder turbines and tandem alternators as against the possible saving that will accrue therefrom in operation. Some time ago I read a remark attributed to Mr. Samuel Insull, the President of the Commonwealth Edison Company, to the effect that he was looking forward to the time when he would employ pressures as high as 1,000 lb. per square inch. He said it was not at all a fantastic suggestion; it was possibly no more remote than the modern turbo-alternator appeared to be some few years back. Whether that be so or not, only the future can tell. But I do think this, that when all the economies have been realized that we are aiming at, with the possible addition of reheating the steam between the high-pressure and the low-pressure cylinders, we shall approach a figure that station engineers have in mind—whether they are optimistic or not I will not predict—namely, 1 lb. of coal per kilowatt-hour at the switchboard.

**Mr. A. E. McKenzie**: Most power station engineers have been considering the possibility of using steam of higher pressure and temperature than our present practice, but bearing in mind the trouble experienced in the early days with turbines of the reaction type, one naturally hesitates to make too big a jump at one time. There is ample evidence that temperatures of about 650° F. can be safely carried without causing serious blading trouble. Many turbines have been running at such temperatures for years. Further, the experience of the British Thomson-Houston Company on their experimental plant proves that a temperature of 680° F. can be safely carried. Generally, I do not think it will pay to increase the pressure to anything less than 350 lb., although in special instances such a course could be economically adopted. Professor Stoney has already pointed out in Schedule 1 the low ratio of circulating water to steam condensed. I agree with his remarks. For the 20,000-kw. set that is now being installed at Stuart-street station for 28-in. vacuum the condenser makers have stipulated for 1,800,000 gallons of circulating water per hour, against 940,000 quoted by the author for a turbine running with 28½-in. vacuum. It will certainly be a good condenser that will give the performance outlined by the author with this quantity of circulating water. The present-day cost of one 215-lb. 20,000-kw. turbine, together with its boilers, economizers, feed pumps, and piping—i.e. those parts only that would be affected by the higher pressure steam—is about £160,000. Mr. Pearce stated that the cost of a 350-lb. boiler would be approximately 20 per cent greater than that of a 200-lb. boiler, and I should like to hear from the author, or from some turbine maker present, what percentage increase is likely to be asked for the 500-lb. pressure turbine. I

would point out that the present price of coal is at least double the basis price given in the Schedule, and this, of course, would mean double the saving outlined. It is extremely probable—and we all hope—that coal will be considerably cheaper in the near future than it is to-day, but it is very unlikely that it will ever be reduced to 10s. per ton, which is the basis price of all the calculations given in the paper. Early in the paper the author says: "Will it pay?" If the boiler and turbine makers are going to charge from 25 to 30 per cent more for the higher pressure parts than they are now doing for the 215-lb. pressure parts, in my opinion it certainly will not. The margin of saving will be too small. In regard to the superheat of 300 degrees F., it has been fully demonstrated that temperatures of about 680° F. can be safely carried, and with 500 lb. pressure there is no need to exceed this temperature. The cooling tower scheme shown in Schedule 3 reveals a great saving after raising the pressure to 350 lb. per square inch. Clearly, in such cases it will undoubtedly pay. I think the price given by the author on page 97, of £4·1 per kilowatt for 20,000-kw. sets, would hardly hold to-day, but perhaps this figure was correct when the paper was written. I quite agree that the steam pipes for higher pressures and temperatures will have to be very carefully designed. The days of large-diameter steam pipes are probably numbered. Manifold headers and small diameter pipes have greater elasticity, and I believe will be generally adopted in the future. The author's condemnation of wrought-iron bolts rather surprised me, and I certainly differ from him, as I have had unfortunate experience with many steel bolts which were subjected to temperatures of 600° and 700° F. and slight vibration. Under these conditions steel bolts soon become very brittle, and they should, undoubtedly, be annealed whenever a joint is remade. I am rather inclined to favour the use of good Low Moor iron bolts, instead of steel, for high temperatures. Cast-iron valves should certainly not be used for superheated steam. We have had considerable trouble through valve makers using for their valve seatings metal having a different coefficient of expansion from the valve bodies, so that after having been subjected to high-temperature steam for a short time the valve seats worked loose and had to be renewed. Most turbine users have had experience of the growth of cast iron under high temperatures—making it almost impossible to keep the casing joints tight at the high-pressure end. In my opinion turbines designed for these high temperatures should dispense altogether with jointing material. The joints should be scraped, and then only a thin smearing of graphite or boiled oil used. With regard to water economizers for the higher pressures contemplated, I certainly think that we should not perpetuate the life of the cast-iron external type in common use to-day. I trust the time is not far distant when we shall dispense altogether with water economizers—using the gases from the boilers for heating the air required for the combustion of the fuel, and bleed the main turbines for raising the feed water to the required temperature. Mr. Baumann commented upon the fact that the vacuum at the turbine was the important point, and not the vacuum at the condenser. I entirely agree with him, as I know of several large turbines in this country badly designed at the low-pressure end—one, in particular, where there is a difference of nearly 2 inches of vacuum between the points mentioned.

**Mr. P. Peakman:** I wish to speak from the point of view of the metallurgist. First of all I may say I am interested in turbines and also in condensers, and I must be very careful in the remarks that I make because possibly I shall have to justify them within the next few years. From the point of view of materials the turbine maker, the boiler maker, and the condenser maker are quite safe in going up to the temperatures and pressures suggested by the author—that is, if we have very carefully selected material. I do not mean that we should depend entirely on the steel maker and tell him we want certain results and then leave it to him to see that the results will be all right. We must very carefully examine and select those materials that he sends. I am glad to note what Professor Stoney has said about the growth of cast iron. If we are going to use these high pressures and temperatures we must eliminate cast iron in our construction—that is, cast iron as we know it to-day. What he has said is perfectly correct, but I think it can be supplemented in this way, that the silicon also plays an important part in the growth of cast iron. How that takes place would require a long explanation, but I may say that the oxidization of the silicon in the cast iron is also a factor causing growth and disintegration. With reference to the higher temperatures and pressures that have been suggested, it must be remembered that during the manufacture of steel we are absorbing or occluding gas. Only a fortnight ago the Faraday Society had rather a long discussion over the occlusion of gas in metals, and it was very clearly brought forward there that if metal or alloys contain occluded gas and we heat up that material this occluded gas is evolved. We can clearly see that if there is occluded gas in the material as soon as we increase the temperature we are going to get gas coming out, and it has been shown that by heating 62 grammes of an ordinary mild steel and subjecting it to a temperature between 400° and 500° C. we obtain somewhere about 7 cubic centimetres of gas, the chief constituent of the gas of course being hydrogen. Now what is important to us is this. If we are going to adopt such high temperatures we are likely to experience trouble? I will say this, that I am fully convinced the metallurgical world can produce a material which can withstand these high temperatures. But don't think of cast iron. The other point I want to mention is that at these higher temperatures and pressures non-ferrous metals up to the present are quite a failure. That means that turbines cannot be constructed from non-ferrous materials or alloys and especially at the high-pressure end of the turbine. Such materials disintegrate very rapidly and become very brittle indeed. In considering the design of higher pressure turbines or even boilers we must thus eliminate as far as possible these metals which we know have caused trouble. Another point which Professor Stoney mentioned and which I wish to emphasize, is the ductility of metals at high temperatures. Possibly not many

members realized that at various temperatures steel is very ductile. At a high temperature it becomes brittle but at a higher temperature still it becomes again very ductile. What we must bear in mind, is that steel does exhibit ductility at various zones. It has been shown on one or two occasions that something happens in an ordinary carbon steel at temperatures of about 360° C., which is somewhere near the temperature suggested by the author at which to run these higher pressure turbines. As far as we can ascertain up to the present there is no danger whatever in going up to the temperatures that have been suggested by the author. Whether this will increase the cost of manufacture I do not know, unless it is that we have got to be more careful in the selection of the materials used. Impact figures at high temperatures or increasing temperatures will be published very shortly. Professor Huntingdon a matter of six or seven years ago did a whole series of tests on carbon steel, getting the impact value at temperatures ranging from about 100° C. upwards. Mr. McKenzie brought forward a point regarding steel bolts. I agree with him. Low Moor iron bolts undoubtedly give better results on work where great fatigue is experienced. If there is any vibration or any fatigue it will not be absorbed so readily by mild steel as it will by Low Moor iron. If we have a bolt or any piece of material that requires to be bent backwards and forwards an enormous number of times, Low Moor iron should be used; but if one cannot obtain such material then a very low carbon mild steel that has been oil toughened should be chosen.

**Mr. W. Bayliss:** Boiler makers to-day have no hesitation in constructing a boiler for pressures up to and including 475 lb. per square inch, the latter pressure being adopted for an electric generating station on the Tees side which Mr. Pearce has mentioned. Apart from central station work, however, there are several industries in this country, and in Lancashire particularly, that are at the present time adopting boiler pressures up to 275 lb. per square inch in connection with electric generation. As regards the economy to be derived from the boiler installation itself in response to these high pressures, there is nothing to be looked for in that direction. There will be a slight loss when evaporating water to these high pressures, but this loss is so small compared with evaporation at 200 lb. per square inch as to be almost negligible. As is well known the difference in the number of therms in a pound of steam at, say, 200 lb. pressure and 475 lb. pressure from water at 32° F. is only about 21 therms. Further, as the superheat is increased there is a little additional increase on account of the greater specific heat, but generally speaking the difference in the cost of producing steam at 200 lb. pressure and steam at 475 lb. pressure is more or less negligible. One direction in which boiler users can progress is to be sure that the boiler is supplied with a suitable feed water. In one station, comparatively small but highly efficient, where the total make-up feed is somewhere in the neighbourhood of 5 to 8 per cent, the engineer has evaporated by means of live steam his make-up feed water so that he is practically feeding into the boiler pure distilled water. He must look out for erosion, but he is alive to that. The result is that he has a boiler with internal heating surfaces always in a condition of maximum efficiency. Under those conditions I do not think an average of 77½ per cent boiler efficiency is impossible. Apart from increased efficiency due to the ideal feed supply, internal boiler cleaning is reduced to a minimum and boilers are in service more hours per year than would otherwise be the case. Consequently, capital is employed to better advantage and of course the generating station may be operated with fewer standby boilers than under ordinary working conditions. In visiting many of the power stations it has occurred to me that too little attention is paid to the coal consumption per shift in relation to the number of units generated. My idea is that each boiler should be fitted with a coal-measuring machine and that each turbine unit should have allocated to it its proper number of boilers. During ordinary working, careful records should be taken of the coal, water, and number of units generated for each turbine unit and each set of boilers. This enables us to analyse carefully the figures obtained and sets up a healthy competition among the station staff on each shift, which is a point to be desired. Further, the boilers and turbines are being operated on practically test conditions. One of the speakers stated that he could not quite understand why contractors required so much money for plant if it was outside their general commodity. Well the way I should put it would be this: If we employ a consulting engineer we pay him for his experience; a progressive engineering company has to do a certain amount of pioneer work in order to perfect its wares before placing them on the market, and it seems to me to be quite a legitimate thing for even a contractor to ask a price which will recoup him for his pioneer work and his experience. Apart from selling iron and steel he is asking us to pay so much for his knowing how. Mr. McKenzie raised a very pertinent point, namely, as regards the loss of tensile strength and general failure in bolts connecting steam pipes. I think this is due to fatigue in the material set up by stress rather than to the temperature. Such bolts can be readily brought to the original state by annealing. Dealing with the question of large steam pipes for high-pressure service, the effect of density of steam has been mentioned by one of the speakers. Steam pipes in future will certainly be of smaller dimensions, as owing to steam increasing in density as the pressures are increased the diameter of steam pipes will correspondingly be reduced for comparable duties. I think Mr. Pearce was correct in stating the percentage of increase in the cost of high-pressure plant for about 350 lb. pressure to be at the present time about 20 per cent. I anticipate that up to 475 lb. this increase will not go up proportionately, as the temperature difficulty has been dealt with and it is merely the pressure increase which has to be considered. Very little experience at present is available for the guidance of manufacturers, as few plants have been produced. There is no doubt, however, that as experience is gained prices will tend to decrease.

**Mr. J. D. Paton:** I should like to ask the author whether he has made any investigations or whether he knows if investigations have been made on steam

at the temperature and pressure which he proposes to use, and if there is any evidence of dissociation of the constituents. I am convinced from my own observations that there is a partial dissociation of steam into its constituents of hydrogen and oxygen, and that oxygen plays a large part in the erosion of metals. Some years ago I caused some amusement by developing a "tadpole" theory due to this dissociation and the high linear velocity of steam when used in turbine constructions (see *Journal I.E.E.*, 1912, vol. 48, p. 856) It is a well-known fact that the lower eutectic of any alloy always melts at a much lower temperature than the final solution temperature of the alloy. Consequently it is quite possible to get distortion of material along eutectic planes while some of the other constituents of the metal still retain their old formation, and "swaging," as already mentioned in regard to Sir Robert Hadfield's experiments, is dependent on this. As a matter of fact, the most recent development in the structure of aluminium pistons for aeroplanes in which I have been interested has been the introduction of elements raising the lowest eutectic melting point and thus retaining the structure of the piston intact while submitted to heats which previously crumbled the piston, having a lower eutectic melting point. The stability of these alloys in the past has been always investigated on a chemical basis, but I am convinced that the observations of Chatelier, which he confined to pyrometric effect, should be carried further and the reciprocal of his Chatelier currents be investigated. If an unstable combination of metals produces a Chatelier current, then, inversely, the Chatelier current evidenced is dependent on the instability of the subject in which it arises. I would refer members in regard to the stability of materials to recent investigations by Ebenezer Griffiths of the National Physical Laboratory, in which I was interested at a very early stage. As a matter of fact I submitted in Manchester many years ago to Dr. Rosenhain my own theory on the instability of platinum-iridium metals as being due to electro-positive-negative relation of the constituents and that the disintegration which arose under certain temperature was the effort of the metal to eject the unbalanced charge. Each element from caesium to fluorine has a fixed positive-negative relation and there are certain eutectics or "natural alloys" at which combinations of these elements have a maximum stability. Under such conditions the Chatelier current which can be evidenced in a wire constituted of two such elements is a minimum, but the increment of either the alpha or the beta constituents will give a corresponding increase in the Chatelier current, and it is a known fact that continued heating and cooling will eventually tend to segregate the crystal of the element in excess. The extrusion of lead from bullion ingots transported from Australia, and the recent remarks by Professor Rhead on the extrusion of sulphide eutectics and chromium and nickel-chromium combinations, are evidences of the same action, and I hold that the future solution of the stability of metals lies as much with the electrical investigator as with the metallurgical chemist.

**Mr. T. R. Wollaston**: While we have offered to us these extraordinary efficiencies on the turbine side, I think there is much greater scope for higher efficiencies on the boiler side. I do not believe there is such a thing as a 75·5 per cent consistent boiler efficiency maintained day after day in this country. But it is frequently obtained on short tests, and I believe it would be possible to get 85 per cent consistently if as much attention were devoted to boiler improvement as to turbines, and on a fraction of the capital outlay implied by the author's proposals. This will not, however, be done with chain grates.

**Mr. R. E. Burcham**: I am interested particularly in generating steam. I have been watching progress for many years, following closely the development from low pressure to high pressure in reciprocating engines, the re-introduction and extended use of superheating, and the growing improvements that have now resulted in the superior economy of the turbine engine especially in large units for electric generation. The curves of possible results from steam engines show that the benefit from further increases of pressure and superheat is a gradually diminishing quantity, that is to say, the gain is not at all directly proportionate to those increases. On the other hand, Mr. McKenzie's figures show that the increased capital charges will be very considerable, and hence the net commercial gain will apparently be comparatively small. A pressure of 200 lb. with superheat is not now very uncommon, and hitherto we have been going up 10, 20, or 30 lb. at a time, always obtaining substantial gain; now it is proposed to spring up to at least 350 lb. pressure and adopt a big increase of superheat. It strikes me that we must expect to meet further troubles such as we have gradually overcome when taking the smaller steps mentioned. Of course, if we are to feel the benefit now, a big step is a necessity. I do not see a likelihood of any serious trouble as regards working water-tube boilers, of suitable construction and fed with good condensate from turbines, up to 350 lb. In fact we have such boilers working well beyond that pressure, used for test purposes, etc. It is mainly a question of construction and of good feed water. Now we come to the economizer. If the feed water is heated in an economizer we also get the high pressure there. Sometimes if the economizer happens to get short of water we also get overheating and unequal expansion of parts. Cast iron for the construction of an economizer for 350 lb. or higher pressure strikes me as a thing that I would not care to have much to do with, and especially so if it were arranged with slightly inclined tubes and superimposed upon a water-tube boiler. We might then get overheating of the long upper tubes, when the water gets low, as compared with the lower tubes which still have water in them. These conditions for a cast-iron structure are at least very undesirable. Even at moderate pressure we occasionally have had very disastrous explosions where cast-iron economizers have been somewhat deteriorated, though not apparently really weak, and it has been very difficult to suggest exactly what caused them to smash up into fragments as they have done. For the high pressures proposed I very strongly advocate that the economizer should be of steel. Cast iron has been tolerated for many years

because it resists somewhat better than steel both external corrosion, due to the condensation of the products of combustion, and internal corrosion due to feed water, etc. But station engineers of to-day should know how to prevent this deterioration of both kinds, by keeping the inlet water temperature above the dew point of the flue gases, which could be done by means of a circulator, and also check internal wasting by suitable treatment of the "make-up" feed water. If we get air into the feed water we must introduce something (say a little tannin extract with soda or something of that kind) so as to take up the oxygen of the air out of the water. I am very strongly in favour of steel economizers for the anticipated new conditions, and it is not only a question of making a structure that will stand hydraulic tests. We can, of course, make a cast-iron structure that will stand a big hydraulic test pressure, but this test is not comparable with the working conditions. I believe the expansion of steam pipes has much to do with the trouble experienced when superheat has been employed. The author seems to have adopted a uniform coefficient in his calculation of the expansion of steam ranges—the expansion, however, is not quite uniform per degree increment, i.e. is not represented by a straight line but by a slight curve, the increments increasing somewhat as the temperature rises; so that the expansion of the ranges would come out rather more than stated in the paper.

**Mr. E. C. Mills:** I notice that the capital charge put down against the increased cost is estimated on a life of 15 years with compound interest at 5 per cent. I suppose that is a normal return merely as interest. The point is, however, what should be put down for depreciation? It is not unusual to take 12½ per cent to cover interest and depreciation, and I am wondering whether the author has contemplated that this high-pressure and high-temperature machinery will be more liable to depreciate than ordinary machinery. It seems to me that something like 15 per cent would probably not be too much to cover interest and depreciation. If I am correct, almost all if not all the saving that is going to be obtained will be absorbed.

**Mr. J. H. Shaw** (*in reply*): I was very pleased to hear Professor Stoney's confirmation of my experience with cast iron when this material is exposed to high-temperature steam. His description of the oxidization alongside the graphite plates certainly appeals to the ordinary engineer, and I have personally had experience with steam chests on turbines that have grown quite as much as 3 per cent when exposed to steam not exceeding 550° F. For all calculations for Schedule 1 the circulating-water outlet temperature is assumed to be 82° F., which is within 10 degrees of the temperature of the steam in the condenser. It is true that condensers are seldom built to work within such a small margin, but I am of opinion that it is possible and that in the near future we shall be building condensers with this small margin. I am in agreement with Professor Stoney that for efficient air extraction it is essential to use a steam jet. The whole of the steam can be used for feed-heating purposes, except that there will be a considerable quantity of air in the steam and this should be separated out before it is condensed by means of condensate.

The method of checking calculations by differences, outlined by Mr. Baumann, is very useful. The Schedules in the paper have again been gone through carefully in view of his observations, and it has been found that the greatest departures between Mr. Baumann's calculations and those in the Schedules have been caused by rounding off the figures in order not to have too many places of decimals. In view, however, of his desire for accuracy the Schedules have been revised, but it will be found that the greatest differences between Schedule 1 as it originally appeared and as it now appears in the *Journal* is 1/100th of a lb. of coal per kilowatt-hour. The error in Schedule 2 was purely arithmetical and attention had already been drawn to it.

Mr. Pearce has pointed out that the Connors Creek power station consumes 1·42 lb. of coal per kilowatt-hour against 1·82 lb. per kilowatt-hour for the hypothetical station given in the paper. During the year ending June 1917 the Connors Creek station used 20,040 therms per kilowatt-hour delivered to the busbars, whereas in the paper the calculations show a consumption of 20,940 therms for the hypothetical station working at 350 lb. pressure and 250 degrees F. superheat. This would be a much more creditable performance, as the American station was consuming coal with an average calorific value of 13,200 therms per lb., while the hypothetical station is supposed to be using coal with a heat content of only 10,000 therms per lb., it being a much easier proposition to run with a higher efficiency with a high calorific value of coal. When suggesting the use of two-cylinder machines either in tandem or cross-compound for high pressure and high superheat, I had in mind quite moderate speeds such as 1,200 or 1,500 r.p.m. It would of course be more satisfactory if the higher pressure machine were run at, say, 2,400 or 3,000 r.p.m., as this would keep down the diameter of the high-pressure cylinder and make the design better able to take care of expansion.

I am sorry that I cannot give Mr. Paton any information concerning dissociation of steam at high temperatures, although no doubt it is the oxygen that assists in eroding all metals.

In reply to Mr. Burcham I would say that an economizer of cast-iron tubes inclined to the horizontal and erected over a water-tube boiler is not a design that would appeal to the average engineer, but I can see no objection to the use of the standard vertical-tube economizer up to 400 or even 500 lb. pressure, provided that centrifugal boiler feed-pumps are used and efficient feed-water regulators. In a modern designed station with large boiler units there is no need to run the economizers at the same pressure as the boiler. The economizers can be designed for 60 to 80 lb. pressure and the water from the economizers led back to a further stage of a multi-stage boiler feed-pump, where the pressure can be raised to the feed-line pressure. I appreciate that the coefficient of expansion for steel is not uniform, but the difference being so slight it is generally neglected in steam-pipe calculations.

South Midland Centre, at Birmingham, 27 November, 1918.

**Mr. L. S. Carr:** The paper appears at a time when the subject of super-power stations is very much to the fore, and the question of the most economical pressure and superheat to adopt calls for the most careful thought—it cannot be considered from the point of thermal efficiency only, for it does not follow that the most highly efficient conditions will naturally be the best from a commercial point of view. For instance, everyone knows that with turbines a very high vacuum is required in order to obtain high efficiency, but this vacuum calls for heavy capital expenditure for condensing plant, and in inland stations heavy costs for cooling towers and pumping. In the same way we have to consider what very high pressures and temperatures will entail in the way of capital costs and maintenance. At present there is very little data available regarding these—at any rate for extra high pressure. We have had three years' experience with steam of a temperature in the neighbourhood of 700° F., and at this temperature have experienced no trouble whatever as regards the erosion effect on blading mentioned by the author. The blading being in perfect condition, the effect of this temperature on certain parts of the fittings supplied in gunmetal was overlooked, and these had to be replaced by steel or one of its alloys, but otherwise the results have been most satisfactory. As the author has mentioned, Glasgow's new power station is designed for 250 lb. per square inch and 250 degrees superheat, and I understand that boiler plant at a new station on the North-East Coast for a working pressure of 475 lb. per square inch and 700° F. is now being installed, which is a big advance on anything attempted in this country before. I hope the capital, running, and maintenance costs will be published, as well as the steam consumption. I should like to see the term "pounds of coal per kilowatt generated" abolished, as it is entirely misleading. I notice it appears in the paper. It is obviously unfair to attempt to compare two districts on such a basis, a station using coal of 12,000 or 13,000 therms with, say, one using coal of between 8,000 and 9,000 therms. The latter station, though it may be burning more pounds of coal per kilowatt, may be the more highly efficient. Reverting to the question of vacuum, a high vacuum can be obtained on a river or seaside station due to the colder water, and to the fact that syphonic action can be taken advantage of, thereby materially lowering the pumping costs. I do not think, however, that for machines of 15,000 kw. rating and upwards it will be found that—at any rate in the present state of the art—the very high figure of 29·1 inches of vacuum mentioned by the author can be taken full advantage of, owing to the huge volume of steam to be dealt with, entailing unmechanically long blades at the low-pressure end. A vacuum of 28·8 inches is nearer the mark. In connection with this question of pressure and superheat, an article was published in the March number of the *General Electric Review* by Eskil Berg of the turbine engineering department of the General Electric Company of Schenectady, which I would advise anyone interested in the subject to read. In it the benefits derived from high pressure and high superheat are very clearly shown by means of tables and diagrams. The increase of water rate is given as approximately 1 per cent gain for every 12·5 degrees of superheat, and the author also points out, as does Mr. Shaw, that a considerable saving in the size of auxiliaries is possible by the use of superheat. Mr. Shaw states on page 80 of the paper that "the natural development of the turbine for higher pressures appears to be in a line with Parsons two-cylinder machine." I do not quite see his reason for this assumption. It does not appear to me that the Parsons type of machine is particularly well suited to take advantage of high steam temperatures on account of the small clearances, and that the impulse type of turbine would therefore be the better, particularly as with the latter type the high initial temperature is confined to the steam chest, the temperature being greatly reduced when it reaches the inside of the turbine itself. In the paper by Mr. Berg this is very clearly shown. In conclusion, generally as regards the use of high-pressure steam and superheat, I am in agreement with the author that a jump to 600 lb. would mean very radical re-designing of turbines, boilers, piping and fittings, and that a compromise at the present stage is advisable, say, 350 lb. per square inch and 700° F. total temperature. For the Birmingham Corporation new Nechells station we propose to use steam at 325 lb. per sq. in. gauge and 700° F. With such conditions little alteration is required to existing patterns. From inquiries made, the capital cost will not exceed what it would be for the more usual 200 lb. per square inch and 250 degrees superheat, this being due to the reduced size of boiler drums, piping, fittings, and condensing plant.

**Mr. H. Bentham:** I should like to ask the author whether he has any actual operating figures, no matter how few, for comparison with the tables. In Schedule 5, columns 3 and 11, a saving of 8 per cent in fuel consumption is shown by raising the steam gauge pressure from 200 lb. with 200 degrees F. superheat, to 300 lb. with 300 degrees F. superheat. The hesitation of most engineers about adopting high pressures and temperatures is on account of the added possibility of breakdown, which would not only wipe out possible economies, but in these days of plant shortage might dislocate the running of the station. I am afraid the higher temperatures will lead to serious expansion troubles, particularly in turbines of the reaction type which depend on fine clearances for their efficiency. Has the author any information to give on this point, and can he state whether high pressure or temperature had anything to do with the recent breakdown of the two 35,000-kw. and one 25,000-kw. turbo-generators in the States? I inspected the "high pressure and superheat" B.T.H. and Babcock combination at Rugby after a long run, and apart from the scoring of the first row of nozzles which received the high-pressure steam and, I believe, the first row of buckets, it was in excellent condition. This set, however, was small and I am afraid expansion trouble will occur

on sets of 5,000 to 10,000 kw. The author suggests compound turbines, I should like to know whether this is to get over expansion troubles, or on account of the size of unit, or for both reasons. He has made no reference to steam-driven auxiliaries and I should like to hear whether he considered this question when preparing the various schedules; if not, I think the figure of 8 per cent would be somewhat affected. I can hardly agree with him when he states that the total works costs (page 79) are not likely to be affected by the use of higher pressures and temperatures. There is no doubt in my mind that maintenance costs would wipe out fuel-saving if one ventured to operate some existing plants at higher total temperatures than 600° F. Additional expansion due to higher temperatures will undoubtedly set up further "racking" strains on the pipe-work. At one large power station I was informed they were discarding all welded steam piping on their main steam ranges, and substituting riveted pipes and flanges owing to serious troubles with the welded type at high temperatures. The installation of evaporators will get over the boiler-feed troubles mentioned by the author. The savings shown in Schedule 5 are much too modest. These should be doubled, as the average price of fuel is nearer £1 than the 10s. per ton allowed for.

**Mr. R. A. Chattock:** I wish to criticize some of the author's figures as I feel that such a valuable paper on such an important subject ought to represent accurately what is being attained in modern power stations rather than include figures which the author has himself described as optimistic. The statement that cooling towers cannot be expected to obtain a lower bottom temperature than 75° F. is hardly correct. In Birmingham we are obtaining an average temperature throughout the year of 71° F., and the vacuum corresponding to this is 28·3 inches. Coal is taken at 10s. a ton. I do not think it is likely that it will ever come down as low as this for many years. I anticipate that the average price when things become normal will be about 15s. a ton, and I think the figures should have been worked out on this basis. A vacuum of 28·5 inches is assumed with a circulating water temperature of 60° F. with river water. I consider that a vacuum of 29 inches should be easily obtained with such a temperature. The overall efficiency of boiler-house plant is assumed to be 77·5 per cent. As an average figure I consider this is practically impossible to obtain. Whilst it is true that on individual boiler tests including economizers, efficiencies of 80 to 85 per cent can be obtained, the average efficiency of the whole of the boiler house over a period of 12 months cannot be expected to be higher than 70 per cent, and probably it is generally somewhat lower than this. The coal per unit is stated in pounds throughout the paper. I consider that it is more useful to state this in therms per unit. In some parts of the country coal of 13,000 to 14,000 therms per pound is used, whilst in other parts the coal is of only 8,000 to 9,000 therms. It is obvious, therefore, that for comparison pounds of coal per unit is quite misleading. I am very glad to see that the author refers to the importance of de-aerating the condensate and make-up feed water. With the very pure water that it is necessary to use in modern high-duty boilers, the liability to internal corrosion of pipes and economizers is very great, and it is of the utmost importance that the carbon di-oxide or the oxygen contained in the water should be removed. The closed-circuit system of handling the water should be adopted, and the temperature should be raised to at least 180° to 200° F. Most of the firms building condensing apparatus are now looking into this question and several schemes are being put forward for the purpose. The advisability of using high pressures and high temperatures is quite recognized amongst engineers. In Birmingham we are proposing to press the boilers up to 325 lb. per square inch, and to superheat up to a total temperature of 700° F. The author refers to the high velocity of the steam in the steam pipes, suggesting 150 feet per second. I quite agree with this view and would point out that with these high pressures there is an additional benefit in keeping the velocity high in order to keep down the diameter of the steam pipes and valves, and so reduce the cost and also the radiating surface of the pipes. The rigidity of the pipes will also be reduced, and it would be more easy to allow for the additional expansion that will take place with the higher temperatures.

**Mr. J. Y. Mackersie:** It would be interesting to know how the author arrives at the figure of 8 per cent on page 77. 1,583 lb. of coal per hour is an estimated figure for the standing losses of the power station under discussion with a working pressure of 200 lb. per square inch. The author proposes to add 8 per cent to this figure when the working pressure is 350 lb. per square inch. I know of no formula, empirical or otherwise, giving the proportion of standing losses on the increased pressure, and I should be glad to learn more on this subject from the author's experience. The author thinks that the boilers used in the new stations will be of the flash type with no steam and water reserve. This seems to be the general trend of opinion and it appears to me, looking at the matter from a station engineer's point of view, that this hand-to-mouth system of steam-raising will be dead against one of the principles of station-running, viz. continuity of supply. I see no reason why a steam reserve should not be provided, either by providing larger steam drums or by some other method of steam storage. From the reports contained in the paper from various manufacturers it would appear that boiler, piping, and valve makers are evidently well prepared to tackle the difficulties regarding the higher temperatures and pressures of steam, but no particulars are given from makers of packing and jointing material. On page 82 an American firm (evidently makers of valves and fittings) dismisses the subject in a sentence, "The packing and gasket problems are also worthy of thought."

**Mr. R. J. Kaula:** Whether one agrees with the whole of the author's figures or not there can be no doubt he has shown conclusively that there is a case in favour of raising the steam conditions; but he does not seem very clear in his reasons for limiting the pressure to 400 lb. per square inch. One or two speakers have taken his remarks on page 73 to mean that such

a pressure could be adopted in existing stations on existing plants provided suitable modifications were introduced. I do not think he meant that; but in any case such modifications would be outside the range of practicable engineering. That increased pressures and, especially, increased steam temperatures involve an increased risk of breakdowns and failures goes almost without saying, but without taking such risks there would be little progress. To attain the best efficiency from a turbine of a given type the length of the blade path, i.e. the product of the stages and the mean blade diameters, depends on the therms per pound of steam to be utilized in the turbine. That is, if the steam conditions are raised either the number of stages or the disc diameters must be increased. On the other hand, the blade lengths and consequently the overall diameters of the turbine vary with the total steam quantity passed. It follows that raising the steam conditions means increasing the turbine dimensions and cost in one direction and decreasing it in another, with the net result that apart from the question of materials there is not much to choose between the costs of the two designs. On the other hand, the two designs are essentially different, and if makers are to produce highly efficient turbines for widely differing steam conditions they will have to carry two sets of patterns for each standard output, which is a serious handicap in the matter of cheap and rapid production. To avoid further expenditure in this direction it would be an advantage if users were to agree upon a standard steam pressure and temperature for new installations, such standard to be adhered to for a number of years.

**Mr. F. Forrest:** One of the most serious considerations which arise when dealing with the question of using steam pressures as high as 350 lb. per square inch is the type of economizer to be used, and I think the author has dismissed this important point with far too brief a reference. It has to be borne in mind that the pressure inside the economizer tubes is a pulsating pressure, which is greatly accentuated if reciprocating pumps are used, even although these are fitted with extra large air vessels, and the tubes are at the same time being subjected to external temperatures due to the flue gases probably as high as 500° or 600° F. The physical properties of cast iron are such that at first sight one would condemn the use of this material for economizer tubes for use under such conditions, and future experience only will show whether they can be made as satisfactory at the higher pressures as they are at the lower pressures now commonly in use. The steel-tube economizer on the other hand, which would appear to be much more suitable for the purpose, suffers under the disadvantage that the metal rapidly corrodes unless means are adopted for completely de-aerating the feed water before it enters the economizer. It is quite likely, therefore, that there will be a decided difference of opinion among engineers as to which type to adopt until extensive experience has proved which is the better for these high pressures. With feed water at 350 lb. per square inch and, say, 250° F., a burst tube would be a very serious matter, and the boiler insurance companies, as well as engineers in charge of plant, will also watch this matter very carefully.

**Mr. J. P. Kemp:** I should like to draw the author's attention to the statement on page 75, to the effect that "the overall efficiency of the boiler-house plant is assumed to be 77·5 per cent, which should be obtained with modern boiler control." Is this seriously put forward as a practical figure, and does the author know of any coal-using power station in this, or any other country, where such results are obtained under average working conditions over an extended period? In a somewhat extensive experience of modern boiler-house control I have not known such a very high result, and I think that an average of 67·5 per cent would more closely represent the average efficiency obtained in quite well-managed boiler houses at the present day. When one takes into consideration the fact that most boilers have of necessity to be blown down (a little) daily, and entirely let down and emptied occasionally for a variety of reasons such as internal cleaning, tube failures, annual inspection, and various other contingencies that arise in every boiler house, 77·5 per cent appears to be far too optimistic for average conditions, which after all is the only fair criterion. 77·5 per cent efficiency would not, in my opinion, be a very discreditable result at the present time for a full-duty official boiler test with a flying start and a flying finish, and no contingencies. The highest average result I have known was obtained in a power station in Brazil where the average for one particular month was 72·0 per cent, but the conditions were extraordinary. The boilers were new and very clean, they were operated at a fairly high "boiler load factor," all air leakages on standing boilers were carefully eliminated, the feed water was clean so that blowing down was very seldom necessary, no boilers were emptied during the month, the boilers were hand fired by Indian stokers who were doing their utmost to earn their bonus, and the entire plant was very carefully supervised for the whole period by competent European engineers. These are conditions which are not ordinarily experienced in boiler-house practice, and, unless a very marked improvement is effected in the various types of boilers, superheaters, and economizers at present in general use, I very much doubt whether the author's figure of 77·5 per cent average efficiency is practicable. In addition to having the best types of plant, practical experience has taught many of us the advisability of having also a really first-class, well-paid, efficient, and contented staff in every boiler house. These men have greater scope for influencing the operating costs and effecting economies than the members of the staff of any other department in a power station. A great deal has yet to be done to make boiler-house work more inviting to the right class of men, as, in the past, this has been looked upon as a grimy job and it has appealed only to a very indifferent type of labour. There is usually no reason why a modern boiler house should not be as smartly staffed and maintained as any other part of the works, and I would suggest that much can be done to make the work more attractive, and the plant more efficient, by making better provision for the general accommodation of the engineers,

chemists, foremen, stokers, cleaning and coal-handling gangs, etc., in or very close to the boiler house itself. This would do a great deal to raise the general status of the men, and make boiler-house work equally congenial to that of the engine room. I would even suggest (in addition to other accommodation) the generous provision of shower baths with hot and cold water, and proper facilities for men of all classes to bathe and change their clothes in decency and comfort without having to leave the precincts of a warm boiler house, with its attendant risk of catching a severe chill. Let the boiler house be so clean and comfortable that the staff are reluctant to leave it, and much more than is commonly supposed will then have been done towards improving thermo-dynamic and general efficiency.

**Mr. W. N. Y. King**: The author has admitted very candidly that his presentation of the scheme for higher pressure is optimistic, and I agree with him. The gains expected are expressed in plain figures in the bottom row of Schedule 1. From the profits shown there must be deducted various losses attendant on the rise of the increased pressures, e.g. extra capital cost and maintenance charges due to special steam-piping fittings, joints, glands, lagging, etc. Further, auxiliary plant, which is as important as the main plant in large turbine lay-outs, will be considerably affected in design. A usual design has the air and circulating pumps driven by a steam turbine, the exhaust steam being taken to heat the feed water before entering the economizer. At higher pressures this preheating is especially necessary. With higher steam pressures auxiliary piping will be a source of greater care and loss of heat due to radiation, and is likely to involve more in upkeep of valves and lagging. The power required to drive the auxiliaries is, I think, estimated on too conservative a basis, the total in the first column, 530 kw., being only 2·65 per cent of the total output. I suggest that 5 per cent would be nearer to the correct proportion, even with a highly efficient plant as is considered here. It would have been more suitable to express the power required in kilowatts and not use the term brake horse-power at all for calculations in connection with technical electrical matters.

**Mr. J. H. Shaw** (*in reply*): In reply to Mr. Carr, many machines have been built to operate at 29·1 inches of vacuum, and at present turbines are being constructed to operate at 29·25 inches. The rarity of the steam at these pressures entails a double-flow machine for the low-pressure end. I did not intend to say that reaction machines had to be used for high pressure and temperature; what I intended to convey was that a two-cylinder machine appeared to be the most suitable, for many reasons. If of the tandem type each cylinder can be provided with its own thrust block and take care of its own expansion, and if cross-compounded each machine can be run at the speed most suitable. I think it will be found that large impulse turbines will in the future be constructed without velocity wheels, so that even with this design the high temperature and pressure will be distributed down the machine just the same as with a reaction machine.

I am sorry that I have no operating figures to give Mr. Bentham, neither can I give him any more information regarding breakdowns in the United States than is already published in the Press. I suggested that above 50,000 kilowatts compound machines were preferable on account of expansion, and for the reason that with this type of machine each unit can be run at the most suitable speed.

Mr. Chattock criticizes my figures of 75° F. for the bottom temperature of cooling towers. I am willing to admit that lower temperatures can be obtained, but at an excessive outlay on cooling towers; and placing the extra gains due to increased vacuum against the extra power required plus the maintenance and capital charges, I think it will be found that a temperature between 75° and 80° F. is the most economical. With regard to the overall efficiency of the boiler-house plant, I am sorry to hear an expert like Mr. Chattock say that 77·5 per cent overall efficiency is impossible. I am convinced that it is possible, and that in the near future we shall have many boiler houses running within $2\frac{1}{2}$ per cent of this figure.

Mr. Mackersie asks how the figure of 8 per cent for the increased stand-by losses at 350 lb. is arrived at. Like Mr. Mackersie I searched for a formula to express this, but could not find one, neither could I make one up from first principles, so I assumed that stand-by losses varied directly with the steam temperature, which I think will be found to be very close to the conditions in practice.

Mr. Kaula has pointed out the one great essential fact. If new power stations are to be designed for higher temperatures and pressures, it will handicap the industry for many years if a committee is not formed at once to decide the pressure and temperature which should be adhered to. I am writing from memory, but to quote a few:—Glasgow is adopting 250 lb. pressure, Tees side 475 lb., Yorkshire Electric Power Company 330 lb., and Birmingham 325 lb. If a committee of expert engineers could be got together three pressures and temperatures could be decided on, depending on the location, cost of coal, and anticipated load factor: (1) a moderate pressure, (2) a high pressure, say 375 lb., and (3) an extra-high pressure of 500 lb.

Mr. Forrest has some doubts regarding the use of cast-iron economizers for high pressure. I cannot see why this should cause any anxiety. Cast iron has been used for hydraulic mains at over 1,000 lb. per square inch for many years, and in these mains there is a considerable amount of shock. In the case of a boiler plant there is no need for the pressure inside the economizer to fluctuate if centrifugal boiler feed-pumps are used, and, moreover, by means of a multi-stage pump the economizers can be worked at a lower pressure than the boiler. With scientific control of boiler operation and of the feed water, I do not think there should be any trouble with either mild steel or cast-iron economizers.

I would refer Mr. Kemp to my reply to Mr. Chattock as regards the boiler-house efficiency, and I would add that with proper design there is no need for a boiler ever to be blown down. I can endorse Mr. Kemp's views regarding the staffing of the boiler house, and I am looking forward to the time when the boiler house will be as clean as the turbine room.

# THE SUPPLY OF SINGLE-PHASE POWER FROM THREE-PHASE SYSTEMS.

By Professor Miles Walker, D.Sc.

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Summary.

The various methods of supplying single-phase power are considered under the five heads enumerated in the next column. Of these, No. (4) and No. (5) are dealt with in some detail. Under No. (4), phase balancers are divided into stationary and running balancers. A qualification is added to Steinmetz's statement on stationary balancers. It is shown that the elimination of the alternating component of the power does not necessarily bring about a "balance of the phases," as defined on page 111. The correct method of balancing the phases in the case of an electric furnace working at 0·7 power factor is developed for both choke-coil balancer and condenser balancer. Running balancers are classified under five sub-headings (*a*) to (*e*), page 112, according to the method used of overcoming the impedance drop in the windings. The graphic diagrams of the different types are given, and the merits and drawbacks of these balancers discussed.

Under head No. (5) a new type of balancing transformer is described. A calculation of a balancing transformer for feeding a 400-kw. electric furnace is worked out. The figures obtained on the tests of the machine at no load and at full load are given.

## Present Demand for Single-phase Power.

The advantages of three-phase power distribution over the single-phase systems in vogue 25 years ago are so generally acknowledged, that a very large proportion of the electrical power stations of the world generate alternating current in three phases. There are, however, some purposes for which single-phase current is to be preferred, as, for instance, in high-voltage alternating-current traction systems. Here the single-phase trolley wire and resulting connections are so much simpler than the double trolley wire and the adjuncts of a polyphase motor, that some engineers prefer a single-phase system. The successful operation of this type of traction in different parts of the world has created a considerable demand for single-phase power.

Another purpose for which single-phase power is required at the present time is the operation of electric furnaces. There can be no doubt that, putting aside all considerations of convenience of electric supply, and looking at the objects to be attained merely from the metallurgical point of view, the single-phase furnace has much to recommend it. Nevertheless, on account of the great objections raised by the suppliers of electric power to the unbalancing effect of a single-phase load upon their three-phase systems, the polyphase furnace is in much more extensive use in this country than the single-phase furnace.

In view of the very extensive use that will be made of electric furnaces for steel manufacture in the future, it is important to see what can be done to minimize the objection of the suppliers of electric power to a single-phase load.

## Methods of Obtaining Single-phase Power.

Where single-phase power must be supplied for any specific purpose, we have a considerable choice of methods of obtaining it.

(1) Single-phase generators driven by prime movers.
(2) Three-phase generators constructed so as to give single-phase power.
(3) Motor-generator sets.
(4) The taking of single-phase current direct from one of the phases of a three-phase supply system, and the use of a balancer for balancing the phases.
(5) A rotating balancing transformer, which absorbs the balanced three-phase power in one winding and supplies a single-phase load from an independent winding.

### (1) Single-phase Generators Driven by Prime Movers.

Where the single-phase load is near some source of mechanical power, such as a large steam generating station or a water-power, it is comparatively a simple matter to install single-phase generators that can be run independently of any other generators in the station. This has been done in the case of several single-phase traction systems; for instance, in the case of the New Haven and Hartford Railway, where special single-phase steam-turbine-driven generators supply the trolley wire direct at 11,000 volts.

The main objections to the single-phase generator are the following: The cost for a given output is higher than for a three-phase generator; for instance, the cost of a 25-cycle single-phase generator of 5,000-kw. capacity, running at 1,500 r.p.m., would be about 30 per cent higher than that of a three-phase generator of the same characteristics. This is partly because the single-phase output from a given frame is less than the three-phase output, and partly because a single-phase generator must be provided with a very heavy and well-constructed amortisseur on the field magnet, the cost of which is a considerable item. Secondly, the efficiency of a single-phase generator is

considerably lower than that of a three-phase generator of the same rating. This is caused partly by the higher iron losses due to the single-phase armature reaction, and partly by the loss in the amortisseur and the metal surrounding it. The actual percentage by which the efficiency is thus reduced cannot be stated without reference to particular machines, because so much depends upon the proportions of iron and copper and upon the details of the design. Looking through a number of quotations that have been made by a manufacturing firm, the author finds that it is not uncommon for the guaranteed efficiency of a large single-phase generator to be $1\frac{1}{2}$ to 2 per cent lower than that of a three-phase generator of the same general characteristics.

It is in general inconvenient to provide special single-phase generators to supply the load, especially when the load is some distance away from the power station.

### (2) Three-phase Generators Constructed so as to Give Single-phase Power.

Where the load is divided between a number of locomotives or a number of furnaces which are not started simultaneously, it is possible to divide the whole into two parts, putting one part on to one phase of a two-phase generator and the other part on to the other phase. It may be that such an arrangement gives a balance of load that is good enough for practical purposes; and if the generator is constructed with an amortisseur so as to take a single-phase load without injury, this arrangement is perfectly satisfactory. Similarly, three independent loads can be taken from a three-phase system.

*Effect of single-phase load on a three-phase generator.*—In this connection it is interesting to inquire how far the voltage of a three-phase generator is disturbed when a single-phase load is thrown on one phase. In Appendix I will be found the graphic construction for finding the voltage change in each phase when a single-phase load is thrown on one phase of a three-phase generator. The figures obtained on a test of a generator are shown to agree very closely with the theoretical figures; and it is established that if the single-phase load (even of low power factor) does not exceed 20 per cent of the normal three-phase load the disturbance to the voltage is inconsiderable. An instance of this kind is found at Bradford, where single-phase furnaces of 400-kw. capacity are thrown on and off three-phase mains without causing a noticeable unbalancing of the voltages.

*Single-phase armature reaction.*—The ratio of the field ampere-turns on single-phase short-circuit to the field ampere-turns on three-phase short-circuit is also given in Appendix I. This is in the neighbourhood of 0·7, but depends upon the pole arc and the efficiency of the amortisseur.

### (3) Motor-generator Sets.

In some cases where power companies have refused to connect a single-phase load on to their systems, motor-generators have been installed. A motor-generator for this purpose may consist of an induction motor direct connected to a single-phase generator; or a synchronous motor may be used to drive the single-phase generator, and in this case the set may be used for improving the power factor of the system by over-exciting the synchronous motor. For general convenience of operation this method is entirely satisfactory: the consumer has complete control over his own voltage; the power factor on the three-phase side can be adjusted at will; and the maximum demand can be kept within bounds, notwithstanding the heavy currents that may be drawn from the single-phase generator at times of short-circuit. The main drawbacks to this plant are the high first cost and the poor efficiency. Owing to the low efficiency of the single-phase generator, especially when built with heavy armature conductors for large currents, the efficiency of the whole set is usually very poor. A 500 k.v.a. size has an efficiency of about 85 per cent.

### (4) Single-phase Current from Three-phase Supply with Balancer.

In order to secure a higher efficiency than can be obtained from a motor-generator, and a better specific use of the material employed, a number of different types of balancers have been proposed for balancing a three-phase system that would otherwise be thrown out of balance by a heavy single-phase load. These may consist either of stationary apparatus, such as choke coils or condensers, or of running machines, which may be either synchronous or asynchronous.

*What is meant by "out of balance."*—Before considering the various types of balancers, it is necessary to define more exactly what we mean by a three-phase system being out of balance. The generating plant in a three-phase power station might conceivably be so large and its impedance so low that quite a large single-phase load might be thrown on one phase, and yet the voltage might remain practically undisturbed; so that from *the consumer's point of view* the system might be considered in balance. It may even be that, through some slight dissymmetry in the winding of the generators, the voltages at no load are slightly unsymmetrical; and that when the single-phase load is thrown on, the balance of the voltages becomes perfect. We see that it is necessary to distinguish between unbalanced currents and unbalanced voltages; and in considering voltages and currents their phases and wave-forms are important as well as their virtual values.

Let us take first a three-phase system in which the voltages and currents are of *pure sine wave-form*. Let the voltages measured from the star point to the terminals be:

$$e_a = E_a \cos(\omega t - \alpha_a),$$
$$e_b = E_b \cos(\omega t - 2\pi/3 - \alpha_b),$$
$$e_c = E_c \cos(\omega t - 4\pi/3 - \alpha_c).$$

Let the currents in the three legs be:

$$i_a = I_a \cos(\omega t - \phi_a),$$
$$i_b = I_b \cos(\omega t - 2\pi/3 - \phi_b),$$
$$i_c = I_c \cos(\omega t - 4\pi/3 - \phi_c).$$

Then the voltages are in balance when

$$E_a = E_b = E_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and

$$\alpha_a = \alpha_b = \alpha_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In a mesh-connected system the angles between the voltage vectors are dependent upon the values of the voltages, because the vector sum of the voltages must be zero. In this case (1) and (2) are not independent. We may, however, consider the star-connected case where the phase angles are independent of the voltages.

The currents are in balance when

$$I_a = I_b = I_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\phi_a = \phi_b = \phi_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In a three-phase star-connected system not provided with a fourth wire, the phase angles of the currents are dependent upon the values of the currents, because the vector sum of the currents must be zero. Therefore conditions (3) and (4) are not independent. We may, however, consider the perfectly general case where a fourth wire is provided and where the currents and angles are independent.

If a symmetrical generating system has impedances of finite value, any departure from the conditions of balance in the currents causes a want of balance in the voltages. On the other hand, if the impedances in the generator and line are unsymmetrical, the voltage at the consumer's terminals will be unbalanced even when he draws currents that comply with conditions (3) and (4) above. If the voltages at the terminals of consumer S are unbalanced (owing, let us say, to an unsymmetrical load drawn by consumer U), a load of symmetrical polyphase machinery having small impedance, when put in circuit by consumer S, will have the effect of bringing the voltages more nearly into balance. This is due to the fact that the line supplies unbalanced currents to S's symmetrical apparatus, so that even if the effect were almost to balance the voltages, S can justly complain that his load is unbalanced. He would, in fact, have unequal heating in his windings owing to the unsymmetrical loading of U's apparatus. Meanwhile, the central station engineer might be congratulating himself on the fact that his voltages and currents were very nearly balanced. If, therefore, we wish to make a complete statement of the want of balance on any system, we must be precise as to the part of the system under consideration, stating whether the voltages are unbalanced as to amplitude or phase, and whether the currents are unbalanced as to amplitude or phase. This is all on the assumption that the voltages and currents are of pure sine wave-form; if not, there are of course very many more ways in which the system and parts of the system may be unbalanced.

Returning to the case of pure sine wave-forms, there is another way of considering the unbalanced load. In a single-phase circuit in which the voltage is $e = E \sin \omega t$ and the current is $i = I \sin (\omega t - \phi)$ the expression for the power is

$$p = \tfrac{1}{2} E I \cos \phi - \tfrac{1}{2} E I (\cos 2 \omega t - \phi).$$

The first term represents a constant flow of power. The second term represents a double-frequency alternating flow.

In a three-phase system we have in general, in addition to the constant flow terms, the three alternating terms:

in leg A, $\tfrac{1}{2} E_a I_a \cos (2 \omega t - \phi_a)$,
in leg B, $\tfrac{1}{2} E_b I_b \cos (2 \omega t - 4\pi/3 - \phi_b)$,
in leg C, $\tfrac{1}{2} E_c I_c \cos (2 \omega t - 8\pi/3 - \phi_c)$.

If now the phases are balanced so that $E_a = E_b = E_c$, $I_a = I_b = I_c$, and $\phi_a = \phi_b = \phi_c$, these alternating terms can be represented by three equal vectors spaced at 120° to one another, which rotate at twice the frequency of the supply (see Fig. 1). As the sum of equal vectors

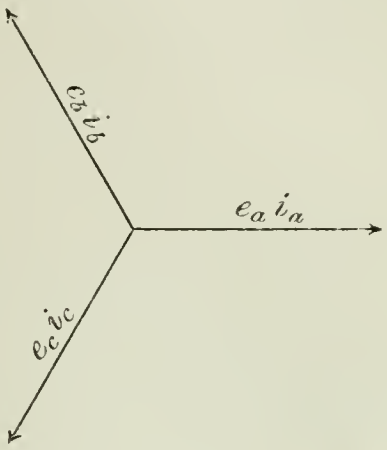



FIG. 1.

so placed is equal to zero, the alternating components of the power balance one another when taken for the system as a whole. Thus we get, as Steinmetz has pointed out,* another test of the balance of the

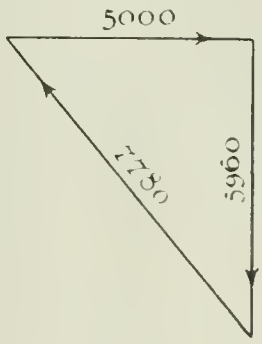



FIG. 2.

loads. If the sum of the three alternating components of the power is zero, the load is balanced in the sense that the single-phase load is on the whole eliminated and the power flows from the generator in an even stream; but if the sum is not zero there is a fluctuating flow of power from the generator.

* "The Theory and Calculation of Electric Circuits," p. 311.

*Elimination of single-phase power components without "balance of phases."*—If the conditions (1), (2), (3), and (4) above do not apply, then the alternating components of the power may or may not balance out one another. It may happen by chance or design that the amplitude and phase of three alternating power components are such that the three vectors representing them would form the sides of a triangle, as in Fig. 2, with the arrow-heads (showing the sense of the vectors) following one another consecutively. In this case the alternating components of the power balance one another, although it may be that neither the currents nor the voltages are balanced.

In Appendix II there is worked out an example in which the power is balanced according to Steinmetz's definition of balance, although the currents and voltages are not balanced.

*Balancers. Stationary apparatus.*—Where a polyphase load has been unbalanced by the addition of a single-phase load, it may be balanced by the addition of a wattless load taken by a choke coil or a condenser. Steinmetz has shown * that where a load is unbalanced and the resultant of the alternating components of the power is equal to $\frac{1}{2}$ E I cos $(2\omega t-\phi)$ it is possible to balance the system (according to his definition of balance) by the addition of a choke coil (of no resistance) fed with a voltage E′ sin $(\omega t-\beta)$, where $\beta=\frac{1}{2}\phi+\frac{1}{4}\pi$ and taking a current I′ sin $(\omega t-\beta-\frac{1}{2}\pi)$, where E′ I′=E I. Or the system may be balanced by the addition of a capacity fed from the voltage E′ sin $(\omega t-\beta)$, where $\beta=\frac{1}{2}\phi-\frac{1}{4}\pi$.

If we apply this method to the balancing of a three-phase circuit which is carrying a single-phase load, it will be found that for some loads the addition of the choke coil gives a true balance, according to the definition on page 111; but that for other loads the balance (while it is such as to bring to zero the resultant alternating components of power) is not such as to comply with conditions (1), (2), (3), and (4) of page 111.

In Appendix III is given a graphic construction, which shows how it is that the addition of a choke coil in the example given by Steinmetz brings about a balance of phases. If, however, we apply Steinmetz's method to the case of a single-phase furnace fed from a three-phase supply, when the furnace is taking a current lagging $45°=\phi$, we find that we do not necessarily get symmetrical currents. Whether we do or not, depends upon the particular voltage components from the three phases that we take to build up the voltage E′ sin $(\omega t-\beta)$.

In Appendix IV is shown a case where the addition of a choke coil fed from the voltage E′ sin $(\omega t-\beta)$, and taking such a current as to bring the sum of the alternating components of power to zero, nevertheless fails to bring about balance of phases as defined on page 111.

It is, however, possible, by taking three transformers of suitable ratios, to build up the voltage $e'$ from components of $e_a$, $e_b$, and $e_c$ such that the final currents in all phases are exactly balanced when the choke coil is in circuit with $e'$. The components of the voltages to be taken in order to meet this condition are seen from Fig. 37 in Appendix V.

* "The Theory and Calculation of Electric Circuits," p. 318.

It will be seen that the addition to the system of the choking coil in question, while it brings about a balance, increases the wattless load on the system. Now that condensers of large capacity can be manufactured at fairly reasonable prices, it would be possible to use a condenser instead of a choke coil, with the effect of improving the power factor at the same time as balancing its load. In Appendix VI is given the construction which shows how it is possible to balance the currents as well as to reduce the alternating components of the power to zero in the condenser case (see Figs. 39 and 40). Such an arrangement, however, has the drawback (apart from its first cost) of requiring to be switched in and out with the furnace load. If it is left always in circuit it will produce as much out-of-balance when the furnace is not taking current as the furnace produces when no compensator is employed. It would, of course, be possible to make automatic gear for switching in more or less capacity as the load on the furnace changed; but such automatic switching arrangements are not looked upon with favour by electrical manufacturers.

*Balancers. Running machines.*—A running machine such as a synchronous motor or asynchronous motor is able to take energy from the circuit at one part of a cycle, store it as kinetic energy, and return it to the circuit at another part of the cycle. In this way it is able to neutralize the alternating component of the power mentioned on page 111. Any symmetrical three-phase motor or generator running on the system and having an armature of low impedance will help to balance the voltages on a system when the voltages are unbalanced. Such a machine balances the voltages by taking unbalanced currents from the line. These unbalanced currents, multiplied by the impedances of their respective armature circuits, give the unequal voltage-drops that represent the differences between the unsymmetrical voltages $e_a$, $e_b$, and $e_c$ of the line, and the symmetrical back voltages $e'_a$, $e'_b$, and $e'_c$ of the motor or generator. If the impedance of the armature is exceedingly low, these differences will be exceedingly small—that is to say, the system will be very nearly balanced.

If the armature impedance is not negligibly small, it is possible to obtain balance by connecting some kind of boosting appliance in series with the balancer to compensate for the impedance drop in the armature. In this way a comparatively small balancer can be compelled to take an unsymmetrical load sufficient to balance perfectly the voltage of the system. The main distinction between different kinds of balancers lies in the kind of boosting appliance employed. The methods of boosting may be roughly classified as follows:

(*a*) Unsymmetrical numbers of turns in the balancer winding.
(*b*) Booster transformer in series with the winding.
(*c*) Addition of choke coils or condensers to some of the phases.
(*d*) Booster generator in series with the winding.
(*e*) The generation of an oppositely-rotating magnetic field of double the frequency.

With any of these methods, the balancer may be either synchronous or asynchronous. A synchronous balancer can be used to correct the power factor of the system, whereas an asynchronous machine usually throws a lagging wattless load on the system.

(*a*) *Unsymmetrical numbers of turns on balancer winding.*—The first method is illustrated in Fig. 3,* which shows a single-phase load D supplied from a

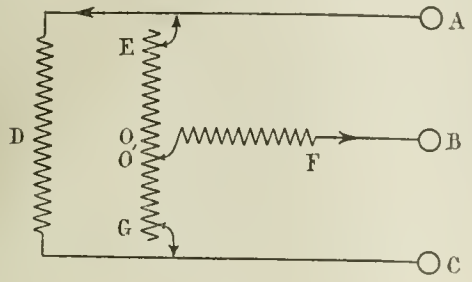



FIG. 3.

three-phase supply, the terminals of which are A, B and C. A balancer (which may be either synchronous or asynchronous) is shown with its windings E, F, G connected so as to balance the load. The windings E and G together may form one of the phases of a two-phase generator, F forming the other phase. In this case the number of turns in F is arranged so as to give a symmetrical three-phase voltage at the ter-

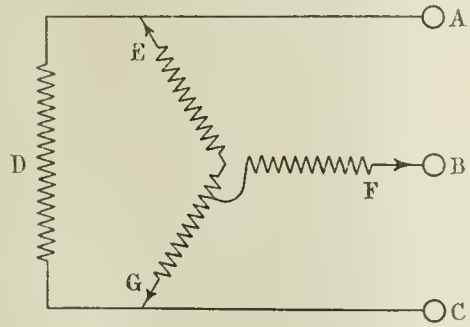



FIG. 3A.

minals. Or, if preferred, the winding E, F, and G may be wound as an ordinary three-phase generator (Fig. 3A). In either case tappings are brought out from E G near the star point so that the inner end of F may be connected in an unsymmetrical manner. Tappings may also be brought out near the outer ends of E and G.

Let us first connect F to the centre point of E G and see what will happen when a single-phase load is thrown on D. To fix our ideas we shall consider the case of a synchronous balancer with the excitation arranged to give unity power factor. If the generators and mains supplying A, B, and C had an infinitely small impedance, then, whatever single-phase load we might draw, the three-phase voltage would remain balanced, and the balancer would run light, taking only a small synchronizing current. In practice, the generators have a certain impedance, which (as shown on page 127)

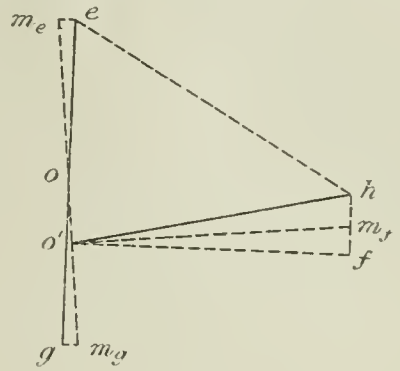



FIG. 4.

causes the voltage A C to fall. The winding E G will then have a small tendency to supply current to D, and the winding F will operate as a motor winding. The synchronous impedance of the balancer will, however, limit the load supplied to D, and it will only be in so far as the voltage on the system is thrown out of balance that any load can be obtained from E G. If now we displace the inner end of F in the manner shown in Fig. 3A, we can obtain a large balancing load from E G while the three-phase voltage remains

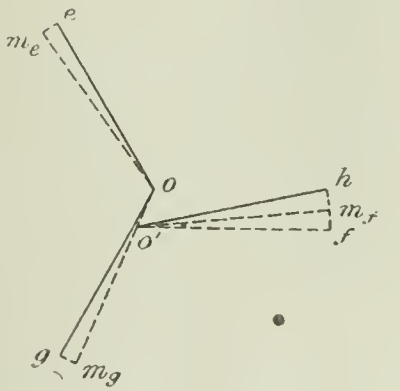



FIG. 4A.

balanced. The vector diagram is shown in Fig. 4. For the purpose of this figure, the arrow-heads in Fig. 3 show the directions of currents and E.M.F.'s taken as positive. Moreover, it should be remarked that the phase of the voltage at the terminals of E G is taken as the standard of phase; that is to say, that a vertical line is arbitrarily taken to represent the phase of this terminal voltage, and the phase positions of all other vectors are set off from this vertical line, according to

* All the clock diagrams in this paper are supposed to rotate anti-clockwise. It will be seen on inspection of the diagrams relating to the various balancers that in some cases the back E.M.F. of phase A is shown ahead of the line impressed E.M.F. in A and sometimes behind the impressed E.M.F. This is as it should be. In Fig. 4, for instance, it is ahead because the field magnet is pushed ahead by the phase B acting as a motor. In Fig. 6 it is behind because the boosting E.M.F.'s are such as to enable phase A to act as generator notwithstanding the position of the field magnet, which being behind the impressed E.M.F. brings into being a synchronizing E.M.F., $V_a V_{a'}$, and this, in combination with the booster E.M.F., gives the desired load on the balancer.

the phase difference between their respective quantities and this terminal voltage. If $oe$ and $og$ represent the terminal voltages of O E and O G respectively when the balancer is on load, it is clear that the generated voltages in these windings must be slightly ahead in phase if O E and O G are to supply currents as generators. The phase position of the field magnet being ahead of the terminal voltage the generated voltages may be represented by $om_e$ and $om_g$ respectively. The field magnet, as will be seen directly, is forced ahead by the F winding and gives rise to this lead in the phase of $om_e$ and $om_g$. If the load current is nearly in phase with the E.M.F., the impedance drop in O E and O G may be represented by $m_e e$ and $m_g g$. The vector $o' m_f$, which is at right angles to $m_e m_g$, gives the generated voltage in F. Now the winding F is carrying a motor load, so that the impedance drop must be set off in a counter-clockwise direction $m_f h$. Let the inner end of F be displaced from the star point O to the point O′ (Fig. 3), and let the voltage in OO′ be $oo'$ (Fig. 4). At no load the voltage generated in F will be $o'f$. At full load, the generated voltage will be $o' m_f$, owing to the displacement of the field magnet, and the terminal voltage will be $o'h$. If now the displacement from $o$ to $o'$ downwards is approximately equal to the displacement between $h$ and $f$, the points $e$, $h$, and $g$ will fall near the corners of an equilateral triangle; that is to say, the voltages are nearly balanced. In practice the displacement of the inner end of F does not exactly compensate for the displacement of $h$ to $f$, owing to slight phase displacements caused by the resistances of the circuits. Balance can be more accurately obtained by using the taps at E and G. The drawback to the use of these unsymmetrical connections is that at no load they cause as much out-of-balance as they cure when the load is on. Proposals * have been made for altering the taps on the windings automatically as the load comes on, but this involves rather undesirable complications.

(*b*) *Boosting transformers in series with balancer windings.*—It is clear that it is possible to compensate for the inductive drop in the balancer windings by injecting electromotive forces of the right amount and phase, by means of transformers, in series with the balancer windings. In 1915 a single-phase furnace project was brought before the British Westinghouse Company, and experiments were made to see how far a synchronous motor could be made to operate as a balancer by means of injected E.M.F.'s. The apparatus was just such as could be found on the test bed at the time, and consisted of a 250-kw. rotary converter acting as a balancer fed from a 300-kw. three-phase star-connected alternating-current generator. The single-phase load consisted of an iron wire rack and a choke coil, and had a power factor of about 0·8. The boosting transformers were the ordinary workshop testing-transformers provided with a large number of taps on the secondary, and were not very suitable for the work. The connections to the terminals of the three-phase generator are shown in Fig. 5. It was found that the rotary converter could be made to balance the currents fairly well. With a single-phase load of 165 k.v.a. on the rack, the currents from the terminals of the alternating-current generator were balanced to within 6 per cent of the mean current. This was good enough for practical purposes, and if it had been possible to get better control of the boosting voltage a better balance could have been obtained. The rotary converter, in addition to balancing the load, provided all the wattless current for the single-phase load, the current from the alternating-current generator being drawn at unity power factor. Owing to the unsteady conditions prevailing at the time, it was not possible to find the exact angles between the various voltages and currents; but there was no very marked departure from the ideal case represented in Fig. 6. Here the vertical line $OV_a$ is taken as the standard of phase, and represents the pressure at the terminal A measured from the star point of the generator. The vectors $V_P$, $V_Q$, and $V_R$ are the line pressures C to A, A to B, and B to C respectively. The directions

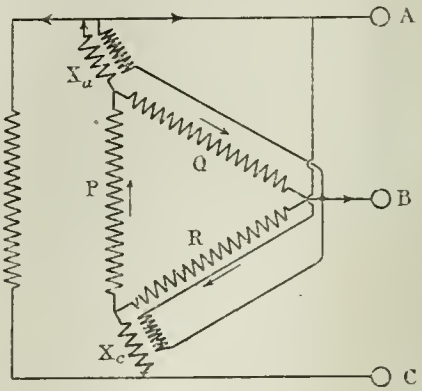



Fig. 5.

that are taken as positive in each wire for the purpose of the clock diagram are shown by the arrow-heads in Fig. 5. The boosting and synchronizing E.M.F.'s are too small to be shown satisfactorily in Fig. 6, and are therefore shown to a different scale in Fig. 7. Neglecting these for the moment and returning to Fig. 6, we may consider the generator and motor functions of the balancer separately, and afterwards combine the generator and motor currents to obtain the actual current at each terminal.

We have in the first place a current of 530 amperes supplied to the single-phase load D; this is shown by the vector $O I_D$ lagging 36° behind the voltage $V_P$. Then we have the three motor currents $I_a$, $I_b$, and $I_c$ flowing from the three-phase generator into the balancer, each in direct opposition of phase to the star back-E.M.F.'s of the balancer. As the efficiency of the balancer in this experiment was very low, these motor currents were about 300 amperes, giving an input of $3 \times 300 \times 180 = 162$ kw. for a single-phase output of $530 \times 310 \times 0{\cdot}8 = 132$ kw. In combining the generator and motor currents we must of course have regard to the arrow-heads in Fig. 5. According to the conventions chosen, $I_D$ is a positive current when flowing

* U.S. patent specifications Nos. 114,167 and 136,016 of 1916.

in D in the direction of the D arrow-head; and as the arrow-head at $X_a$ runs concurrently with it, $I_D$ and $I_a$ must be added, as shown in Fig. 6, to get the actual current $I_A$. The arrow-head at D is, however, opposed to the C arrow-head, and so to get the current at C we must subtract $I_D$ from $I_C$. This gives us O $I_C$, shown by the chain-dotted line. The current at B

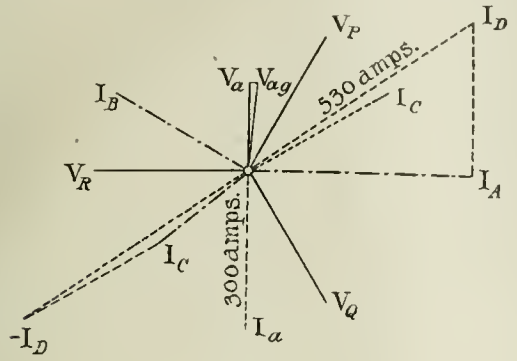



Fig. 6.

is of course $I_B$. Thus we get the currents $I_A$, $I_B$, and $I_C$ that would flow in a star-connected balancer. The fact that the rotary converter is mesh-connected does not affect the deductions made below. The inductive drop in the armature of the converter was about 3·8 volts for each 100 amperes drawn from a slip-ring; and the resistance drop was 0·35 volt for each 100

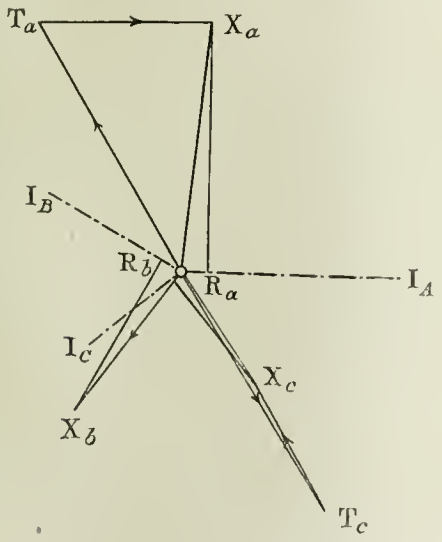



Fig. 7.

amperes. Referring now to Fig. 7, we set off the resistance drop O $R_a$ along the vector $I_a$, and the reactive drop $R_a X_a$ to get the impedance drop O $X_a$ in phase A. If this impedance drop is to cause no disturbance to the balance of the voltages, it must be supplied by the boosting transformer (shown at $X_a$ in Fig. 5) acting in conjunction with the synchronizing voltage $V_a V_{ag}$ (see page 116). The synchronizing voltage $T_a X_a$ (due to the displacement of the field magnet behind the terminal voltage) is transferred from Fig. 6 and drawn to the large scale of Fig. 7. We then find that if the boosting transformer supplies the voltage O $T_a$, the two voltages O $T_a$ and $T_a X_a$ will supply the required impedance drop. In the same way we can find the boosting voltage O $T_c$ required from transformer $X_c$. It will be seen that for this particular single-phase load the boosting voltage is almost parallel to the voltage $V_Q$ (Fig. 6). The primaries of the boosting transformers were connected to the terminals A and B, and the number of turns was adjusted so as to give the best possible balance. This arrangement, however, makes no provision for balancing the resistance drop in phase B. The reactive drop in phase B is almost balanced by the synchronizing voltage. This is because the displacement of the field magnet behind the terminal voltage becomes automatically greater and greater,

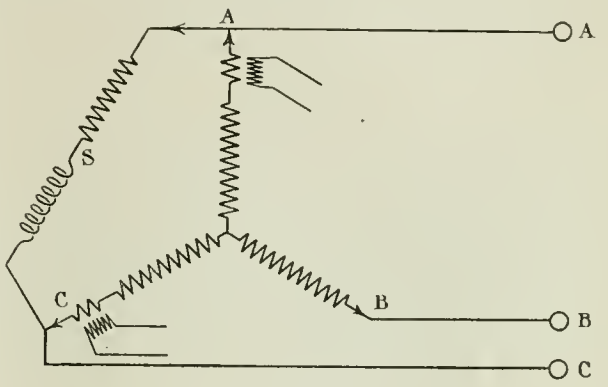



Fig. 8.

until the synchronizing voltage is great enough to supply the requisite motor current, which in this case was 300 amperes. It was found that if the single-phase load was thrown off with the boosting transformer still in action, the rotary converter took from the alternating-current generator an unbalanced load of a magnitude comparable with the single-phase load thrown off. In fact, for every change of the single-phase load it was necessary to alter the taps of the boosting transformer, and for different power factors of the single-phase load it was necessary to take different combinations of phases in order to supply a boosting voltage in the right phase.

A project for a balancer for a 2,400-k.v.a., 0·7 power factor, single-phase furnace was considered in some detail, in order to arrive at the approximate cost and efficiency of such a balancer, and to ascertain the amount and phase of the boosting voltages. The balancer proposed in this case was to be of the synchronous type, built exactly like a synchronous motor, with a heavy amortisseur and with a rather large section of copper in one of the phases of the armature. It was intended that the balancer should carry an excitation sufficient to raise to unity the power factor of the load on the three-phase system. The circuit diagram, with the directions taken as positive in each wire, is shown in Fig. 8. Fig. 9 gives the clock

diagram for the balancer when balancing a single-phase load of 2,400 k.v.a. at 0·7 power factor. The pressure of the three-phase mains is 6,600 volts. The figure is drawn to the scale of one millimetre = 200 volts ; one millimetre = 10 amperes. The single-phase current $I_S$ amounts to 364 amperes, lagging 45° behind the voltage $V_{ac}$. The currents $I_a$, $I_b$, $I_c$ are the balanced three-phase currents taken from the supply mains,

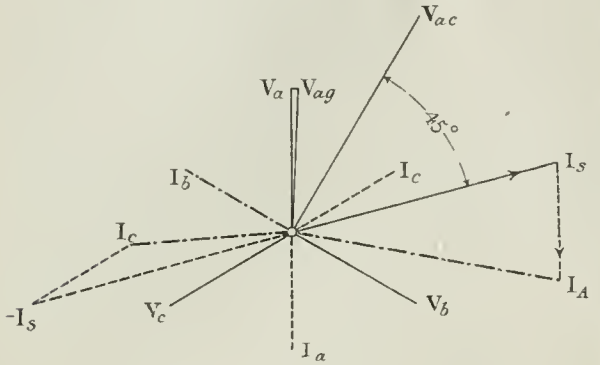


FIG. 9.

opposite in phase to the no-load back-E.M.F.'s $V_a$, $V_b$, and $V_c$ generated in the balancer. The sum of $I_S$ and $I_a$ gives the vector $I_A$, the actual current in phase A of the balancer. The difference between $I_c$ and $I_S$ gives $I_C$, the actual current in phase C of the balancer. The current $I_b$ is of course the actual current in phase B. This disposition of currents is brought about partly by the boosting E.M.F.'s and partly by

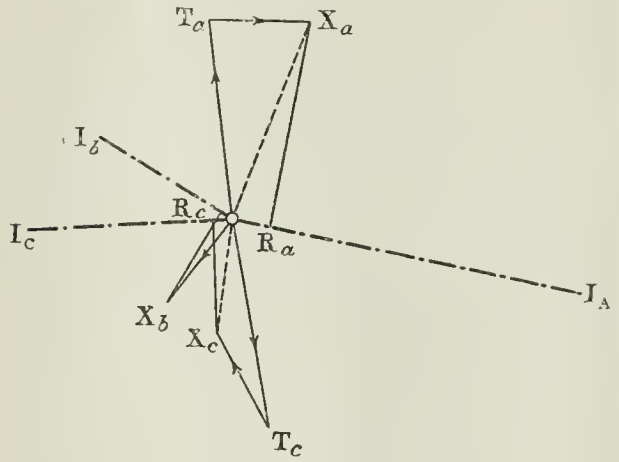


FIG. 10.

the synchronizing E.M.F.'s operating between the motor and the generator. The synchronizing E.M.F. in phase A is shown by the short vector $V_a$ $V_{ag}$ approximately at right angles to O $V_a$. O $V_{ag}$ gives the phase position of the generated voltage in the balancer on full load. It should be noted that as the balancer is running as a motor the phase position is as shown, even on the phases of the balancer that are to operate as generators. It is by virtue of the boosting E.M.F. shown in Fig. 10 that phases A and C are able to operate as generators. The reactance drop in one phase of the armature of the balancer is calculated to be about 11·5 per cent of the 3,800 volts generated in that phase, for a current of 364 amperes. The resistance drop, including eddy-current losses, will amount to about 2 per cent. In order to arrive at the amount and phase positions of the required boosting voltages, we must refer to Fig. 10, which is drawn to a larger scale ; namely, one millimetre = 15 volts ; 2 millimetres = 15 amperes. The currents $I_A$, $I_C$, and $I_b$ are transferred from Fig. 9. We mark off O $R_a$ to give the resistance drop in phase A, and $R_a X_a$, at right angles, to give the reactive drop in phase A ; so that $X_a$ O gives the impedance drop. To overcome this, it is necessary to have a boosting E.M.F. O $T_a$, which when added to the synchronizing E.M.F. $T_a X_a$ gives a voltage of right amount and phase to overcome the impedance drop $X_a$O. Similarly in phase C the boosting voltage O $T_c$ must be injected in order that, combined with the synchronizing voltage $E_c X_c$, it may overcome the reactive drop $X_c$ O. The synchronizing voltage O $X_b$ is sufficient to drive the current O $I_b$ through the reactance of phase B. From this it is seen that the requisite boost in phases A and C amounts to about 400 volts, and its phase is 10° in advance of the E.M.F. $V_a$. It might be supplied by a transformer connected between terminal A and a tapping on winding B near the star-point.

The calculated efficiency of a balancer of this size was 93 per cent, as against an efficiency of 87 per cent for a motor-generator. The estimated cost (war-time prices) was 65 per cent of the cost of a motor-generator to do the same work. As it would be necessary to supply, in addition to the balancer, a transformer to reduce the pressure from 6,600 to 220 volts, the cost of the balancer with exciter and starter, step-down transformer and boosting transformer, would not differ very much from the cost of the motor-generator, and the combination would have an efficiency only 3 or 4 per cent higher than that of a motor-generator.

It was thought by the author that it should be possible to combine in one machine the balancing and power-factor-correcting functions of the synchronous motor with the functions of a step-down transformer and boosting transformer. This combination has been made in the balancer described later in the paper.

The drawback to the connection of boosting transformers permanently in series with various phases is, that when the single-phase load is taken off the system the amount of out-of-balance current taken by the various phases is the same as the out-of-balance current that there would be on full load if no boosting transformers had been used. This could be avoided by having adjustable taps on the transformer that could be controlled by hand or automatically as the load came on and off.*

(*c*) *Addition of choke coils or condensers to some of the phases.*—It will be seen in the methods described under the last heading (*b*) that while we have voltages that are balanced when measured outside the boosting transformers (say at the terminals A, B, and C in Fig. 8), the voltages measured at the terminals of the

* U.S.A. patent specifications Nos. 114,167 and 136,016 of 1916.

balancer itself are not balanced. A want of symmetry here is necessary in order to make the balancer take its load. There are numerous ways in which this want of symmetry can be produced at the terminals of the balancer by the addition of choke coils or condensers in some of the phases, while at the same time the symmetry of the voltages is preserved at the mains. A typical method due to Lawrence * will serve to illustrate the principle of all these methods. It has been proposed for balancing the voltage at the terminals of a three-phase motor on a locomotive fed from a single-phase trolley line. Here single-phase power from transformer T, Fig. 11, is being converted into three-phase power. A rotating balancer A B C (which may be either synchronous or asynchronous) is used to equalize the flow of power. A special choke coil X Y with two windings is placed in series with lines $L_a$ and $L_c$ leading direct from the terminals of the secondary of the transformer. The line $L_b$ is fed from a mid-point of the secondary and passes through one of the phases of a two-phase balancer on its way to the motor. The arrow-heads on the circuit diagram denote the directions on each wire taken as positive for the purpose of the clock diagram. The transformer T may be taken to be supplying power to the three-phase motor M or to any other three-phase apparatus. The distribution of voltage in the three-phase circuit will depend upon the kind of machines connected. We can distinguish broadly three cases :—

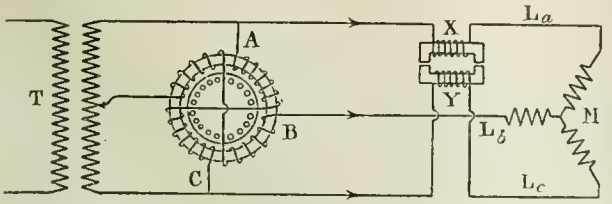



Fig. 11.

($\alpha$) Where the load on the three-phase circuit consists of balanced machines (such as synchronous motors) having infinitely small impedance.
($\beta$) Where it consists of dead resistance.
($\gamma$) Where it consists of machines having finite impedance.

In case ($\alpha$) no balancer is needed, and full load can be supplied from T without upsetting the balance of the voltages. In case ($\beta$), if there were no balancer, no current would flow in the line $L_B$ and we should have a simple single-phase load across $L_A$ $L_C$. If now a balancer be added and the non-inductive load made very small, we get the voltage distribution shown in Fig. 12. If the balancer is a synchronous one, it takes a small synchronizing current in phases $o\,a$ and $o\,c$ (which constitute one phase ; but as $o$ is taken as the star point we must strictly regard them as two phases at 180°). It should be pointed out that in what follows the phase of $o\,a$ is taken as the standard of phase to which all other phases are referred ; that is, the vector representing the voltage at the terminals of the transformer secondary is taken as vertical. At no load, the phase position of the field magnet will be the same as $o\,a$. The phase position of the field magnet is the position from which the generated voltage in B is determined. This generated voltage is at right angles to the generated voltage in A.

If now the load is increased, B will begin by taking its share of the load, and in acting as a generator will pull over the field magnet to, say, a position such as $o\,m_a$ in Fig. 13. Phases A and C will now be acting as motors. The phase of the generated voltage in B takes up a position such as $m_b$. As there is a motor

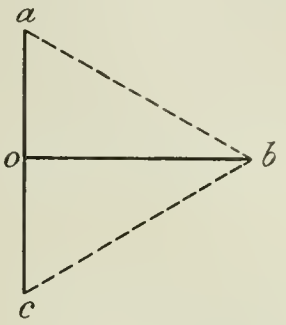



Fig. 12.

load on windings A and C, the armature reaction $m_a\,a$ added to $o\,m_a$ gives the terminal voltage of A at $o\,a$, as before. The armature reaction in B is $m_b\,b'$, so that the terminal voltage of B is $o\,b'$. This displacement of the vector $o\,b'$ in the case of a resistance load does not have much effect upon the load taken by each phase, because that is chiefly controlled by the resistance in circuit ; but if the resistance is replaced by a running machine having a small impedance

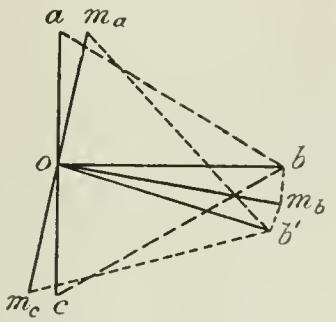



Fig. 13.

in its windings the displacement of $o\,b'$ tends to take the generator load off the phase B, so that in the ordinary way, if nothing more is added to the apparatus, the balancer will not take much load until the phases of the receiving machine are distorted by a single-phase load by an amount corresponding to $b\,b'$.

Now consider the effect of putting a choke X Y in series with $L_a$ and $L_c$, as shown in Fig. 11. Let the load consist of a symmetrical three-phase resistance. So long as the voltage phases are balanced, this three-

* U.S.A patent specification No. 110,815 of 1916.

phase resistance will take equal currents at 120° apart from each of the lines. Let these currents be $I_a$, $I_b$ and $I_c$ shown in Fig. 14 drawn from the true star point O'. The coils on X Y (for forward currents, according to the arrow-heads in Fig. 11) are wound so as to give opposing magnetomotive forces on the choke coil. We must therefore reverse one of the vectors, say $I_c$, in getting the sum of the magnetizing effects of the two coils. This is shown in Fig. 14 by the vector $I_a - I_c$. The reactive voltage on the choke coil is nearly at right angles to this magnetomotive force, and is shown at $O'x = a\,a' = c'c$. Adding $O'x$ to $o\,a$ we get $o\,a'$, and subtracting $O'x$ from $o\,c$ we get $o\,c'$. We now see that the voltages between the terminals of the resistance $a'b'$, $b'c'$, and $c'a'$ are symmetrical. There are, of course, several minor difficulties. For instance, when the load is a running machine the phase of the load current may not be such as to give the required correction; but roughly the choke coil works in the right direction, and theoretically it should always be possible, by a suitable arrangement of choke coils

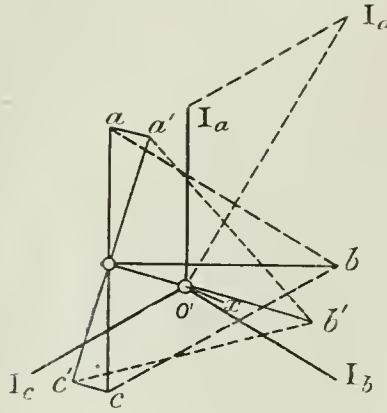



Fig. 14.

and condensers, to bring the added voltages $a\,a'$ and $c\,c'$ into the right phase. The advantage of this method over the boosting-transformer method is that the injected voltage in the choke coil rises automatically with the load. Instead of electrostatic condensers it is of course possible to use electromagnetic machines such as synchronous motors and phase advancers.*

*(d) Booster generator in series with the winding.*—It is clear that, instead of using boosting transformers in series with the various phases, it is possible to use a synchronous booster. In this way the phase and amount of the voltage injected into each leg can be controlled more easily than with transformers in series. Several methods have been proposed, based upon this principle.† The most widely known is that of Alexanderson, described in a paper read by Alexanderson and Hill before the American Institute of Electrical Engineers‡ in October 1916. While Alexanderson's booster may from one point of view be regarded simply as a booster injecting E.M.F.'s which compensate for the impedance drop in the balancer windings, Alexanderson himself prefers to look upon the operation as the injection of oppositely-rotating polyphase components. These oppositely-rotating components we prefer to consider under another heading.

In Fig. 15 are shown the three phases, A, B, and C of the stator of the synchronous balancer connected to

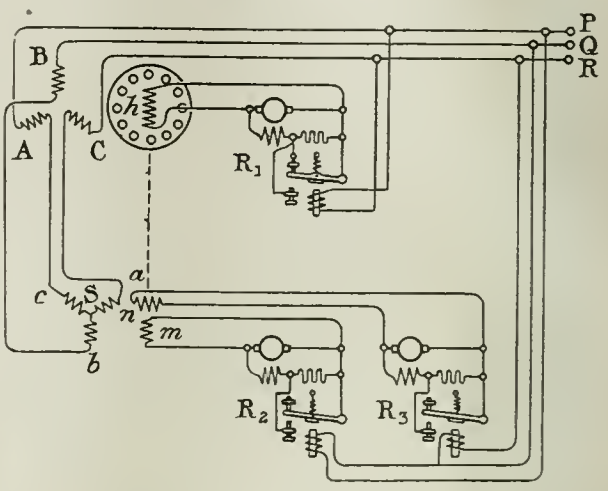



Fig. 15.

a supply system P Q R, which is supposed to be thrown out of balance by having a single-phase load connected between P and R. The function of the balancer is to correct the voltage by supplying current as a generator from phases A and C and taking current as a motor in phase B. These generator and motor currents are

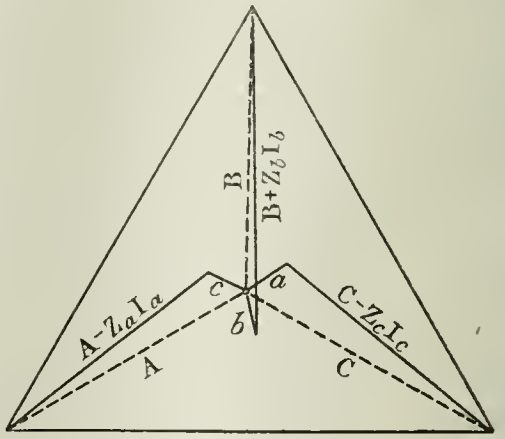



Fig. 16.

controlled by means of a synchronous booster, the stator windings of which are shown at *a*, *b*, and *c*. The field magnets of the main machine and booster are rigidly connected on the same shaft and revolve in synchronism with the supply. The booster windings are connected between the inner ends of the balancer windings and the star point S. It will be seen that phases A and C of the balancer are connected to phases *c* and *a* respectively of the booster, while phase *b* of the booster is

* U.S.A. patent specifications Nos. 112,220, 123,031, and 129,976 of 1916.
† U.S.A. patent No. 1,093,594 (1912).
‡ "Single-phase Power Production," *Transactions of the American Institute of Electrical Engineers*, 1916, vol. 35. p. 1315.

connected to phase B of the balancer, so that its E.M.F. opposes the E.M.F. of the balancer. The field magnet of the balancer is excited by the winding *h* fed from an exciter controlled by a Tirrill regulator $R_1$. The field magnet of the booster has two windings, *m* and *n*, like the windings of a two-phase rotor. The continuous current in these windings is controlled by the two Tirrill regulators $R_2$ and $R_3$ so that the orientation of the magnet field with respect to the iron core of the rotor can be shifted through an arc of 90 electrical degrees according to the behaviour of the regulators, which in their turn depend upon the distribution of voltage between P, Q, and R. It will be seen that the connections shown in Fig. 15 will (for a suitable orientation of the magnetic field of the booster) give a relation of the booster voltages to the balancer voltages such as that illustrated in Fig. 16.

In Fig. 16 the short vectors representing the booster voltages are lettered *a*, *b*, and *c*. These are in series with the balancer voltages C, B, and A respectively, and have the effect of causing phases A and C of the

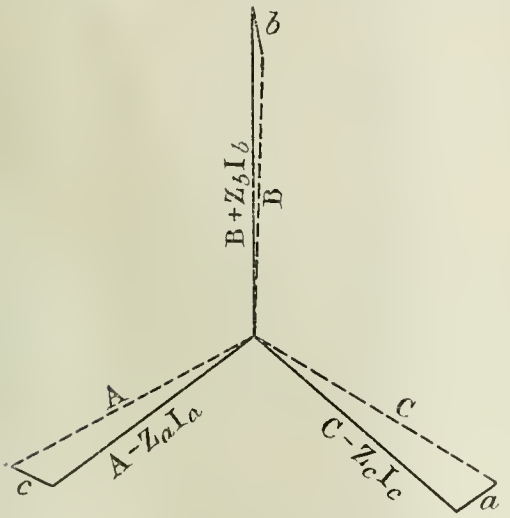



Fig. 17.

balancer to take a generator load, and phase B to take a motor load. When A and C are taking a generator load of low power factor, the terminal voltages would be disturbed in phase and reduced by the impedance drops $Z_a I_a$ and $Z_c I_c$ (see Fig. 16), but the phase and value of boosting voltages *c* and *a* are such as almost to restore the balance of the voltage at P and R. When B is taking a motor load with a leading power factor, the terminal voltage would be increased to $B + Z_b I_b$, but the booster voltage *b* is subtracted from this and restores the balance between P, Q, and R. The vectors may either be laid out as in Fig. 16, in which they radiate from the star point just as the windings radiate in the diagram of connections, or they may be laid out as in Fig. 17, in which form they are more comprehensible in comparison with Fig. 28. The advantage of the booster-generator method of supplying the inductive drops in the balancer over the methods described under headings (*a*), (*b*), and (*c*) is, that in it the boosting voltages are most easily controlled in value and phase. However, since the boosting generator must have the same number of poles as the balancer, it cannot be built very cheaply, even though the output is small; and the cost of the exciters and regulating gear is by no means negligible.

(*e*) *The generation of an oppositely-rotating magnetic field of double the frequency.*—Several methods of balancing single-phase power by supplying currents of double frequency having the sense of rotation opposite to that in the main three-phase system have been described in patent specifications and published writings. As there is a great deal of confusion in writings upon this matter, it may be well, in the first place, to make a precise statement upon the point that is of chief importance in these cases, namely, the effect of an oppositely-rotating magnetic field in a running balancer. And in this connection we must consider the magnetic field produced by a polyphase armature when supplied with unbalanced currents.

*Expression for the resultant magnetic field of a polyphase armature.*—It is not possible to find an exact simple expression for the resultant field of a polyphase generator on load, because the disposition of the armature conductors in slots and the shapes of the iron parts of the poles lead to a complex field-form the shape of which changes as the field revolves. Any simple expression involving only the fundamental term of the Fourier series expressing the whole phenomenon must necessarily be of limited application; but nevertheless it aids us in getting a conception of the main happenings in the machine. For this reason it has been customary for writers upon the subject to regard the armature magnetomotive force of a three-phase armature carrying a balanced load as giving rise to a sinusoidal field distribution superimposed upon the field produced by the exciting winding. Smith and Barling * have shown that the maximum ordinate of the fundamental wave of magnetomotive force under one pole, due to the armature ampere-turns, is equal to

$$\frac{0{\cdot}43\ I_a Z_a}{\text{Number of poles}}$$

where $I_a$ is the virtual value of the armature current and $Z_a$ is the total number of conductors in the armature. The maximum value of the magnetomotive force in reality changes between the values

$$\frac{0{\cdot}437\ I_a Z_a}{\text{Number of poles}} \quad \text{and} \quad \frac{0{\cdot}407\ I_a Z_a}{\text{Number of poles}}.$$

This variation gives rise to a triple-frequency alternating effect, which may be regarded as being produced by six stationary single-phase poles per main pole-pair situated at the points where the windings of the various phases lie adjacent to one another. In what follows we shall neglect this triple-frequency alternating effect and confine our attention to the fundamental wave of magnetomotive force.

To fix our ideas, let us consider a two-pole armature having an ordinary full-pitch three-phase winding lying in three phase-bands A, B, and C per pole. If

* *Electrician*, 1914, vol. 74, p. 42.

the three-phase load is balanced, we may take the armature reaction as giving rise to this fundamental uniformly-rotating field. If the only load is a single-phase load thrown on to terminals A and C, it will give rise to a single-phase magnetomotive force along

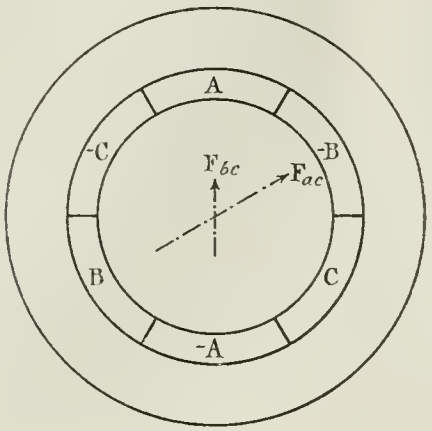



FIG. 18.

a path the centre line of which is indicated by the arrow O $F_{ac}$ in Fig. 18. If now an additional single-phase load is thrown on another phase, it will give rise to another single-phase magnetomotive force along a path having a fixed centre line. This in combination with O $F_{ac}$ will in general result in an elliptically-rotating field. The

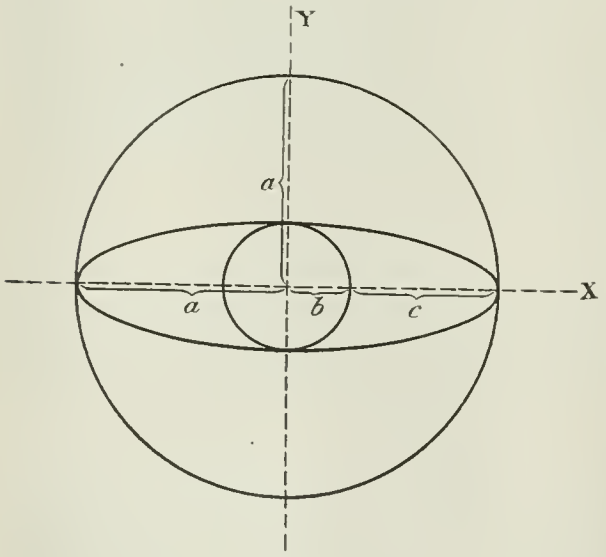



FIG. 19.

addition of a third magnetomotive force changes the shape of the ellipse. In the special case where the single-phase loads on all phases are equal and have equal angles of lag, the ellipse becomes a circle, and we get a simple rotating field, as stated above.

Consider now the general case of any elliptically-rotating field. Let the ellipse be that shown in Fig. 19. Whatever be the slope of the major axis with respect to the horizontal line, it is always possible to take our abscissæ $x$ along the major axis and our ordinates $y$ along the minor axis, and to express the curve in the form $x^2/a^2+y^2/b^2=1$, where $a$ and $b$ are the lengths of the major and minor axis respectively. If we now write $a=b+c$, where $c$ can be found in any given case,

$$\frac{x^2}{(b+c)^2}=\cos^2\omega t \quad \text{and} \quad \frac{y^2}{b^2}=\sin^2\omega t,$$
$$x=b\cos\omega t+c\cos\omega t,$$
$$y=b\sin\omega t.$$

The elliptically-rotating field can be regarded as consisting of two parts: one part a simple rotating field whose vector is given by the co-ordinates $x_1=b\cos\omega t$, $y_1=b\sin\omega t$, and the other part a single-phase stationary field lying along the major axis of the ellipse, given by the expression

$$x_2=c\cos\omega t;\ y_2=0.$$

Now the single-phase field can be broken up into two oppositely-rotating fields:

$$x_2=x_4+x_5=\tfrac{1}{2}c\cos\omega t+\tfrac{1}{2}c\cos(-\omega t),$$
$$y_2=y_4+y_5=\tfrac{1}{2}c\sin\omega t+\tfrac{1}{2}c\sin(-\omega t).$$

Adding $x_1$ to $x_4$ and $y_1$ to $y_4$, we get:

$$x_6=x_1+x_4=(b+\tfrac{1}{2}c)\cos\omega t,$$
$$y_6=y_1+y_4=(b+\tfrac{1}{2}c)\sin\omega t.$$

These form a uniform field rotating forwards, while $x_5=\frac{1}{2}c\cos(-\omega t)$ and $y_5=\frac{1}{2}c\sin(-\omega t)$ give us a uniform field rotating backwards. Thus we see that the magnetic field produced in a polyphase machine having symmetrically disposed coils carrying an unbalanced load can be regarded as the resultant of two uniform fields of different amplitudes rotating in opposite directions.

In their paper* read before the American Institute of Electrical Engineers, Messrs. Gilman and Fortescue state that "an unbalanced polyphase system can be resolved into two balanced systems of positive and negative phase-rotation." It will be seen that this proposition is much wider than the one stated above with regard to the magnetic field, and does not seem to be established by the "proof" given by the authors. By employing the symbolic method, the authors merely describe in algebraical terms a stationary clock diagram; and because of the limitations of the method they employ they cannot establish the proposition.

For our present purpose, however, the proposition established above concerning the magnetic field produced in a polyphase machine is sufficient for the understanding of methods of phase-balancing considered under this heading.

An unbalanced load in a polyphase stator produces a backward-rotating magnetic field in the rotor; and the converse proposition is also true, namely, that a backward-rotating magnetic field in the rotor will produce an unbalanced load in the stator. One way, therefore, of making a balancer for a polyphase system

* "Single-phase Power Service from Central Stations," *Transactions of the American Institute of Electrical Engineers*, 1916, vol. 35, p. 1329.

is to build a synchronous motor having a special winding on the rotor through which currents can be sent which impress a backward-rotating magnetomotive force. The special winding on the rotor in these machines resembles the winding on a slip-ring rotor for an induction motor. The terminals of the winding may be carried either to slip-rings or along the shaft, according as the special auxiliary generator operating as an alternating-current exciter is separate or rigidly connected to the rotor. Various methods* have been proposed for supplying the double-frequency current that is necessary for producing the backward-rotating field. For instance, an alternating-current generator having twice as many poles as the main machine may have its armature directly connected to the rotor and the connections arranged so as to give the required direction and phase to the rotating field. A change in the strength of the poles of an exciter belonging to this auxiliary generator changes the amount of unbalanced load taken by the balancer. With suitable automatic gear of the Tirrill type the balancer can be made automatic. In another method the armature of the auxiliary generator has the same number of poles as the balancer and is driven at the same speed, but the poles of this generator are fed with three-phase current of the same frequency as the main supply. These three-phase currents (which may be in series with the load) produce a magnetic field rotating in a direction opposite to the direction of rotation of the armature. Thus a double-frequency current is produced in the winding of the rotor of the balancer which is proportional to the three-phase load. All these methods involve the use of several auxiliary machines in addition to the main translating apparatus required to furnish the single-phase load at its right voltage; and in the single-phase furnace projects with which the author was concerned they did not give the characteristics that were required, and were ruled out in favour of the type of balancer falling under heading (5).

(5) A Rotating Balancing Transformer,

which absorbs the balanced three-phase power in one winding and supplies a single-phase load from an independent winding.

A balancer of this kind is of special interest in connection with single-phase electric furnaces.

The main advantages claimed for the single-phase furnace are as follows:—In the first place, only two electrodes are required instead of three; and as these can be brought into the furnace at two diametrically opposite points the liability of the arc to cause a short-circuit through the hot semi-conducting lining is very much reduced. This enables the voltage between the terminals to be raised to a value almost double that which is practicable for a polyphase furnace. The increase in the voltage leads to a corresponding reduction in current for the same power input; the smaller current leads to economy in conducting cables and contacts and enables a much smaller electrode to be used than is possible in the polyphase furnace. As the electrode losses are dependent upon the surface of carbon exposed and also upon the amount of air leakage through the furnace, the reduction in the number and size of the electrodes and in the number and size of leakage holes

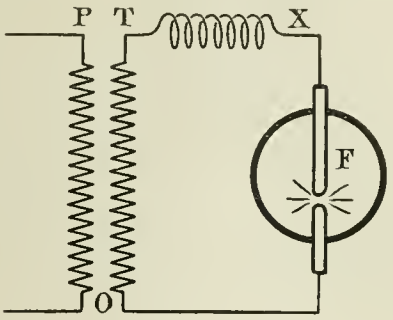



Fig. 20.

results in a great saving in electrode consumption. In the second place, the single-phase furnace has an

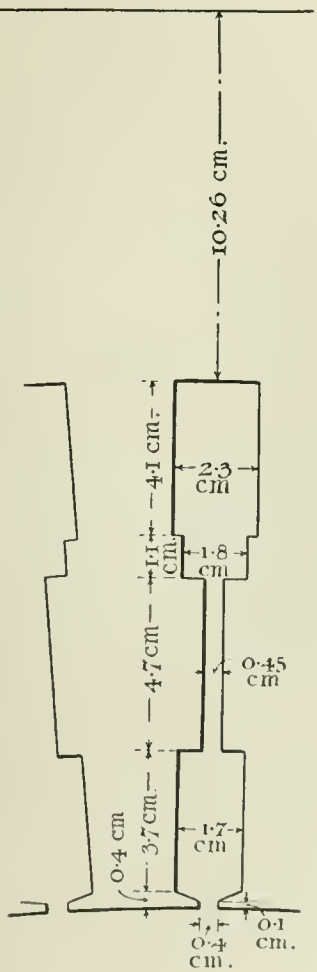



Fig. 21.

exterior shape which approaches a spherical form; the radiation losses are thus reduced to the smallest possible for a given content.

* U.S.A. patents Nos. 108,567, 113,454, 113,455–6, 113,457, and 117,641 of 1916.

*Requirements in balancer for single-phase furnace work.*—When the purpose is to supply a single-phase current to an electric furnace, the source of supply being an ordinary three-phase system, there is an advantage in using a special kind of balancer which shall fulfil the functions of (1) voltage transformer, (2) balancer, (3) reactance, and (4) power-factor corrector. These functions can of course be performed by a motor-generator set designed with suitable characteristics; but the first cost of a motor-generator set is higher than that of a balancer of the same output, and the efficiency is lower. More clearly to understand the functions of such a balancer, something should be said of the advantages (from the user's point of view) of working a single-phase furnace with an inductance in circuit sufficient to make the current lag by 45° behind the voltage.

Consider the circuit shown in Fig. 20, where O P is the primary winding of a transformer, O T its secondary winding, T X a choking coil, and F a single-phase furnace. In the vector diagram, Fig. 22, let O T represent the

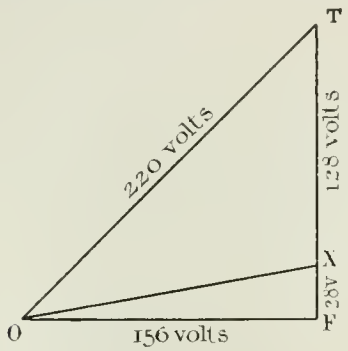



Fig. 22.

voltage generated by the secondary, X T the reactive drop in the choke coil (with which may be included any reactive drop in the transformer). Let F X represent the reactive drop in the furnace, and O F the resistance drop in the furnace and the rest of the circuit. If this diagram represents the full-load working conditions, then the full-load current is lagging 45° behind the voltage, and is represented to some scale by the line O F. When the inductance and resistance are adjusted to give these conditions on full load, and the inductance is maintained constant, the voltage O T being constant, the input to the furnace cannot exceed * the full-load value however the resistance of the circuit may be varied. In fact, if we change the resistance of the furnace from infinity to zero, the current will increase from 0 to 1·41 times full-load current, and the power at various values of the current will be given by the curve in Fig. 23. The full-load value of the current gives the highest point of the curve. Any reduction of the resistance of the furnace beyond this point causes a decrease in the input, although the current is slightly increased. If the furnace is short-circuited, the input falls to zero and the current cannot exceed 1·41 times full-load current.

*The importance of stability.*—These conditions give stability in operation, and are of great importance in preserving the lining of the furnace. No really satisfactory refractory substances can be obtained for the lining of electric furnaces. The best commercial substances, such as dolomite, magnesite, or silica brick, have melting-points not very far above the temperature at which it is desired to work the furnace. If by any unfortunate chance part of the lining reaches a temperature above its melting-point, it begins to blend with the contents of the furnace, causing trouble with the pouring and heavy expense in re-lining. Now the maintaining of the furnace at its proper temperature depends upon the maintaining of the balance between the electrical input and the energy absorbed and radiated. If the characteristics of the circuit are such that an increase in the current is accompanied by an increase

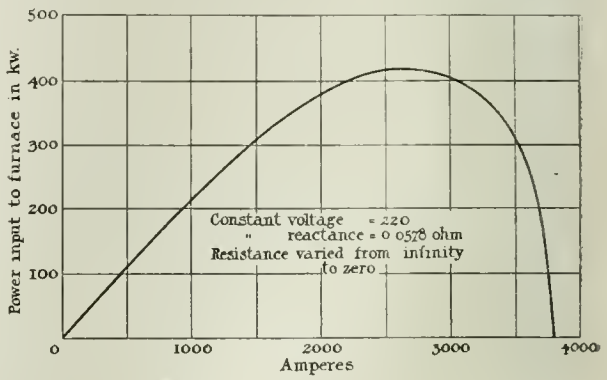



Fig. 23.

in the electrical input, the greatest care must be exercised, when the furnace is at full load, to keep the current near its full-load value; and this is difficult by reason of the unstable nature of the arc. Automatic regulators are often installed to keep the current within bounds, but even these are not found to be sufficient during the first twenty minutes after the furnace has been started up from the cold; and in some three-phase furnaces, where no great amount of inductance is connected in circuit, it is necessary to have three operators (one at the regulating wheel of each carbon), with their eyes fixed on the ammeter, to screw up and down the carbons every few seconds in order to keep the currents approximately balanced. After the furnace has been heated fairly well, the lengths of its arcs are greater, and the regulating can then be handed over to a regulator of the Thury type.

Where sufficient inductance is put in series with the furnace, the circuit becomes automatically stable and no such regulators are required. The ideal condition for steady running is attained when the inductive drop at full load is equal to the resistance drop, as shown in Fig. 23. In some cases the transformers that supply the furnace are built in such a way as to have their magnetic leakage great enough to give the required

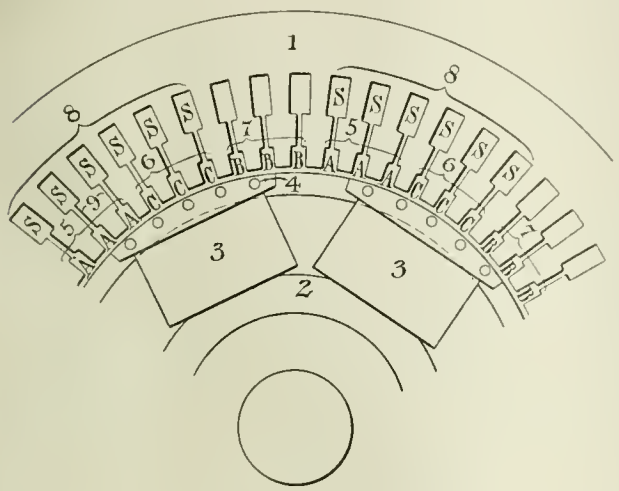
* The proof of this is as follows:—

$$\text{Power} = E\, I \cos\phi = E \frac{E}{\sqrt{(R^2+X^2)}} \cdot \frac{R}{\sqrt{(R^2+X^2)}} = \frac{E^2 R}{R^2+X^2}$$

This is at a maximum when $R = X$.

inductive drop. In designing transformers for this purpose, care must be taken to see that the cross-section of any iron added to the leakage paths is sufficiently great to give a fairly straight-line law for the increase of the leakage flux with the current, right up to the point 1·41 times full-load current; otherwise it may be found that when the furnace is short-circuited the current taken is much more than 1·41 times full-load current, and trouble may arise with the power company supplying the three-phase power. A case came to the notice of the author in which failure to provide a sufficient cross-section for the reactive iron resulted in undue disturbances to the power system and great loss of furnace linings.

From the power company's point of view, the inductance is not an unmixed blessing. By reducing the power factor it calls for more copper in the mains for a given load, and reduces the output of the generators.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## 3-phase to Single-phase Balancer

Date 4 Jan 1916.. Type..... ~~CSN.~~ ~~STH MOTOR ROTARY~~ 8 ..Poles..... Elec. Spec .....
K.V.A. 444 ; P.F 0·9; Phase 3to1 ; Volts 6000/0 220..; Amps per ter 2750 ....; Cycles 50 .; R.P.M. 750 ...; Rotor Amps ..... ;
H.P. ... Amps p. cond. 47 ...Amps p. br. arm..... Temp rise 45C.....Regulation..... ..... .....Overload 90% for 10 secs

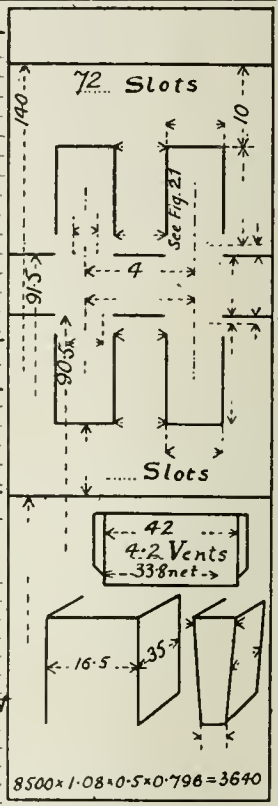
Customer Snyder Elec. Furnace; Order No. 338/16 ...; Quot. No.....; Perf. Spec. ..... ..; Fly-wheel effect ..... .....

Frame 140/42 Circum. 288 .; Gap Area 12,100 .; poss. $A_g B$ ..... ; poss. $I_a Z_a$ ..... .....; $\frac{I_a Z_a}{K.V.A.} = 188$ $\frac{D^2 L \times R P M}{K.V.A.} = 6 \times 10^5$
Air..... ; $A_g B$ 1·03 × $10^{-8}$ .....; $I_a Z_a$ 54,200 .....; Circum. ..... ....;

$K_e$ ; 5940 ....Volts = 0·9 × 12·5 × 1152 × 1·03 ..... ; Arm. A.T. p. pole .. .... ..... ..... Max. Fld. A.T. .....

### Armature. ~~Rot.~~ Stat.

| | | |
|---|---|---|
| Core. Dia. Outs. | 140 | |
| Dia. Ins. | 91·5 | |
| Gross Length | 42 | |
| Air Vents 6 × 0·7 | 4·2 | |
| Opening Min ___ Mean | | |
| Air Velocity 36 m. per sec. | | |
| Net Length 37·8 × ·89 | 33·8 | |
| Depth b Slots | 10 | |
| Section 340 ___ Vol | 140,000 | |
| Flux Density 9800 n.l. | 8800 f.l. | |
| Loss ·04 p. cu. cm. Total | 6500 + | 9000 |
| Buried Cu 2870 Total | 11500 | 18,370 |
| Gap Area 12,100 ; Wts | 5900 | |
| Veot Area 83,000 ; Wts | 8200 | |
| Outs. Area 5870 ; Wts | 5800 | 19900 |
| Teeth. No of Segs ___ Mn. Circ. | 294 | |
| No of Slots 72 × 1·7 = | 123 | |
| K | 1·71 | |
| Section Teeth | 5800 | |
| Volume Teeth | 23,000 | |
| Flux Density | 17,800 | |
| Loss. ___ p. cu. cm. Total | 5000 | |
| Weight of Iron | 2100 | |
| Conductors. Star or Mesh ___ Throw | 1-12, 2-11 | 3-10 |
| Cond. p Slot | 16 | |
| Total Conds. | 1152 | |
| Size of Cond 0·26 × 0·5 | 0·127 | |
| Amp. p. sq. cm | 370 | |
| Length in Slots 42 | | |
| Length outside 66 Sum | 1·08 m. | |
| Total Length | 1255 + | 159 |
| Wt. of 1,000 m 113 Tot. | | |
| Res. p. 1,000 m 1·34 Tot. | 1·9 | 2·22 hot |
| Single-phase ·0044 ÷ 8 = ·00055 | | |
| Watts p. metre | 53 | |
| Surface p metre | 1040 | |
| Watts p. Sq. cm. | ·056 | |
| ·05 × ·03 | 13°C. | |
| ·0012 | | |




### Field ~~Stat. or~~ Rotor.

| | | |
|---|---|---|
| Dia. Bore | 90·5 | |
| ½ Total Air Gap | 0·5 | |
| Gap Co-eff $K_g$ | 1·08 | |
| Pole Pitch ___ Pole Arc | | |
| $K_f$ | no load | full load |
| Flux per Pole | 8·6 × $10^6$ | 6 × $10^6$ |
| Leakage n.l. ___ f.l. 1·3 | | 9·9 × $10^6$ |
| Area 570 Flux density | 17400 | |
| Unbalanced Pull | | |
| No. of Seg. ___ Mn. Circ. | | |
| No. of Slots ___ × = | | |
| Vents | | |
| $K_e$ ___ Section | | |
| Weight of Iron | | |

| | Shunt. | Series. | Comm. |
|---|---|---|---|
| A.T. p Pole o. Load | 5420 | | |
| A.T. p Pole f. Load | 8500 | | |
| Surface | 32,000 | | |
| Surface p Watt | 7 | | |
| $I^2 R$ | 4900 | | |
| I. R. | 129 | | |
| Amps. | 38 | | |
| No. of Turns | 224 | | |
| Mean l Turn | 1·10 | | |
| Total Length | 2080 | | |
| Resistance | 2·8 cold | | |
| | 3·4 hot | | |
| Res. per 1,000 | 1·36 | | |
| Size of Cond | 0·14 sq. cm. | | |
| Conds. per Slot | | | |
| Total | | | |
| Length | | | |
| Wt. per 1,000 | 116 kilo | | |
| Total Wt | 232 | | |
| Watts per Sq. | 0·143 | | |
| Star or Mesh | | | |
| Paths in parallel | 1 | | |

### Magnetization Curve.

| | Section. | Length | 5500 Volts. B. | A.T. p. cm. | A.T. | 5940 Volts. B. | A.T. p. cm | A.T. | 6200 Volts. B. | A.T. p. cm. | A.T. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Core | 340 | 50 | 8150 | 2 | 100 | 8800 | 3 | 150 | 9200 | 3·5 | 175 |
| Stat. Tth | 5800 | 7 | 16,500 | 50 | 350 | 17,800 | 100 | 700 | 18,600 | 130 | 910 |
| Rot. Tth | 6500 | 1·5 | 14,800 | 20 | 30 | 16,000 | 40 | 60 | 16,600 | 50 | 75 |
| Gap | 12,100 | | | | 3370 | 8500 | | 3640 | | | 3800 |
| Pole n.l. | | | | | | | | | | | |
| Yoke | 360 | | | | 90 | | | 150 | | | 200 |
| No Load | | | | | | | | | | | |
| Pole f.l. | 570 | | 15,800 | 30 | 360 | 17,000 | 60 | 720 | 17,800 | 90 | 1080 |
| | | | | | 4300 | | | 5420 | | | 6230 |

### Commutation.

| | |
|---|---|
| Dia | $L_n$ |
| Speed | $L_k$ |
| Bars | $L_c$ |
| Volts p. Bar | $L_s$ |
| Brs. p. Arm | $L_r$ |
| Size of Brs. | $p_s + b_p - c_p$ |
| Amp sq. cm. | $B_c$ |
| Br. Loss | $B_c^1$ |
| Wts. sq. cm. | |

| EFFICIENCY. | ½ load. | Full. | ¾ | ¼ | ¼ |
|---|---|---|---|---|---|
| Friction and Windage | | 6 | | 6 | |
| Iron Loss | | 12·5 | | 12·5 | |
| Field Loss | | 5 | | 4 | |
| Arm. &c. I²R | | 10·9 | | 2·7 | |
| ~~Brush I²R~~ Losses on load | | 8 | | 2 | |
| | | 42·4 | | 27·2 | |
| Output | | 400 | | 200 | |
| Input | | 442·4 | | 227·2 | |
| Efficiency % | | 90·4 | | 88 | |

Mag. Cur. ___ Loss Cur.
Perm. Stat. Slot =
" Rot. Slot × =
" Zig-zag =
2 × × =
1·77 × =
End × × =
Amps; Tot.
$\tau$ = ; $x_A$ =
$S_1/S_2$ ; $r_A$ = +

Imp. $\sqrt{\quad + \quad}$ =
Sh. cir. Cur.
Starting Torque
Max Torque
Max. H.P.
Slip
Power Factor

coupling between these phases and the single-phase coils is more complete than the coupling between the single-phase winding and phase B. Another way of looking at the matter is this: When current passes through the single-phase winding, it drives magnetic flux * across the three-phase slots of phases A and C and causes an inductive drop in these phases; so that there will flow from the line a current of such value and of such phase that it produces an impedance rise sufficient to balance the inductive drop produced by the single-phase magnetomotive force. Since the resistance drop is small, compared with the reactive drop, the excess current that would be taken by phases A and C would be almost in exact opposition of phase to the single-phase current.

One way of preventing this action is to inject into phases A and C an electromotive force which shall at all times be exactly equal and opposite to the electromotive force generated in the three-phase winding by the interlinked flux from the single-phase magnetomotive force. The most direct way of doing this is to wind a few turns of wire interlinked with the main leakage path of the single-phase winding, and electrically connect these to phases A

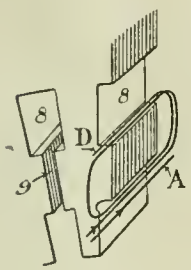



Fig. 25.

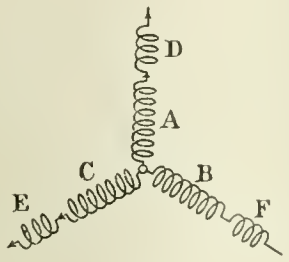



Fig. 26.

and C so that the E.M.F. generated in the turns by the main leakage shall oppose the E.M.F. generated in the three-phase winding by the small leakage across the three-phase slots. As the leakage flux across the leakage air-gap is great, compared with the leakage across the three-phase slots, only very few turns of compensating winding are required to balance the E.M.F. in the 16 conductors per slot of the three-phase winding. The counter magnetomotive force set up by these few turns is so small, compared with the magnetomotive force of the single-phase winding, that it can be neglected in roughly estimating the number of compensating turns required. In Appendix VIII is given the method of calculating the number of compensating turns required. The manner of winding and connecting the compensating conductors can be seen from Figs. 25 and 26.

*Tappings on the three-phase winding.*—In order to provide a means of making small adjustments in the balance of the load on the three-phase winding after the machine was built, three tappings were taken off each of the phases near the star point. These were at 3, 6, and 9 turns respectively away from the inner end of each phase. As there are 192 turns per phase, the tappings give a choice of cutting out 1·56 per cent, 3·12 per cent, or 4·68 per cent of the phase voltage. In practice it was found that the connection that gave the best result with only 3 compensating turns connected was that shown in Fig. 27. The effect of this slight dissymmetry in the connections was to give a slight dissymmetry at no load, as shown by the figures on page 113. This dissymmetry is of no importance in practice, and can be eliminated in future by a better adjustment of the compensating winding. When there is no load on the single-phase winding, there is no E.M.F. in the compensating winding; * and as it is the same magnetomotive force that operates upon the compensating winding as operates upon the three-phase winding and creates a tendency to unequal back E.M.F., the right adjustment of the compensating winding should bring about a nearly exact balance of the phases. The currents in the damper on the field poles also tend to

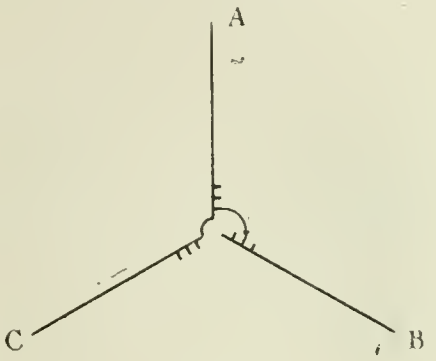



Fig. 27.

create a disturbance in the balance of the load; this disturbance is of a very complex nature, but fortunately is not of very great moment.

*The damper on the field poles.*—The damper consists of 9 drawn copper bars of taper section. These are held in dovetail slots in the pole face, and pinned and sweated to a copper casting encircling each pole. The copper castings are bolted together from pole to pole so as to form a complete squirrel-cage winding. In order to avoid any inductive action between the individual stator slots and the bars of the damper, the slots on the field poles are skewed through a complete stator slot pitch. It was found that with this arrangement the damper showed no signs of heating at no load, and only very slight heating at full load. On a previous machine in which this precaution was not taken, there was a considerable loss in the damper at no load, owing to the inductor action of the stator teeth.

*General method of design.*—Apart from the special features above mentioned, the design of the balancer follows very closely the design of an alternating-current generator or synchronous motor. The full details of

* It should be noted that any change which occurs in the field flux due to the single-phase load (except in so far as it is exterior to the damper) affects phase B as much as phases A and C.

* Except a very small inductive drop due to the three-phase load, which can be compensated for by the addition of a small choke coil in phase B.

MESSRS. SANDYCROFT, LTD.

TEST SHEET.

Date. 15 March, 1917.
For Snyder Electric Furnace Company.

*No-load Losses.*

Order No. 338/16. Motor No. 1,393. K.V.A. 444. Volts 6,000/166. R.P.M. 750. Cycles 50.

| Balancer | | | | | | Driving Motor | | | | Armature $I^2R$ | Difference | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed | Volts, K = 120 | | Exciting Amps. | Exciting Volts | Resistance | Single-phase Volts | Volts | Amps. | Field | Total Watts | | | |
| 758 | 49·7 | 5,970 | 26·5 | 83·8 | 3·15 | 219 | 209 | 48·7 | 18 | 25,400 | 535 | 24,865 | Driven light with its exciter and starting motor at full voltage |
| 758 | 0 | 0 | 0 | 0 | — | — | 210 | 19·5 | 18·1 | 10,200 | 85 | 10,115 | Driven not excited |
| 758 | — | — | — | — | — | — | 205 | 8 | 18 | 4,100 | 15 | 4,085 | Belt off motor |

24,865
10,115

14,750

Exciting watts = 2,220

Exciting watts 2,220

Iron loss .. 12,530 watts

10 115
Friction and windage, including exciter and 4,085
starting motor .. 6,030

| Temperatures | Part | Temperature ° C. reached | Rise ° C. | Resistances at 14° C. | Ohms |
|---|---|---|---|---|---|
| After two hours' run at 6,000 volts, no load | Stator core .. .. | 39 | 22 | Three-phase winding A–B .. | 1·194 |
| | Rotor winding .. | 43 | 26 | ,, ,, B–C .. | 1·185 |
| | Exciter armature .. | 44 | 27 | ,, ,, C–A .. | 1·292 |
| | Exciter commutator | 44 | 27 | One-phase .. .. .. | 0·5435 |
| | Air .. .. .. | 17 | — | One-phase compensation .. | 0·102 |
| | | | | Single-phase winding, one coil | 0·00442 |

TESTS ON SITE. 13 May, 1917.

Order No. 338/16. Serial No. 1393. Three-phase single-phase balancer. 444 k.v.a.

| Speed | Exciting Amps. | Three-phase Side | | | | | | Single-phase Side | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Volts | Amperes | | | Kilowatts | | Volts | Amps. | Kilowatts | |
| | | | A | B | C | A–B | C–B | | | | |
| 750 | 29 | 6,100 | 3·2 | 3·4 | 4 | 9 | 14 | 224 | 0 | 0 | Running light |
| 750 | 39 | 5,960 | 45 | 45 | 49 | 200 | 232 | 160 | 2,450 | 390 | Full load. Arc pulled out to give maximum load |
| 750 | 39 | 5,980 | 13 | 13 | 18 | 38 | 83 | Not readable | 3,620 | 75 | Carbon short-circuited |

the design are given in the calculation sheet on page 124. It is unnecessary here to do more than supplement the explanation given in the author's book of the general method of design.

*Ampere-turns on the field magnet.*—These are calculated in Appendix IX.

*Heating and cooling of the frame.*—The calculation of the heat generated at full load follows the rules given in the book referred to, except that on this machine one has the copper losses of two armatures, and rather heavier eddy-current losses in end plates than on simple generators of the same size. As against this, the air-gaps provided in the leakage path around the single-phase winding afford a very effective cooling surface not found in ordinary machines. This can only be utilized well if an efficient fan is provided to blow a very positive blast of air through the ventilating ducts. The machine was accordingly built with end bells designed so as to enclose the air from the fan blades on the field magnet and to compel a great part of it to traverse the ventilating ducts, while the remainder passed over and between the armature coils before it escaped at ducts provided at the periphery of the end bells.

*Armature losses.*—The various losses and the manner in which the heat is carried away are given in Appendix X.

*Efficiency.*—The measured friction and windage, iron and field losses are filled in their respective places on the calculation sheet. In addition to these losses, an allowance of 8 kw. has been made for extraneous loss at full load, bringing up the total losses at full load to 42·4 kw. Thus the efficiency works out at 90·4 per cent. So far as could be ascertained from measurements made on integrating meters over a number of runs on the furnace, this figure is very near the mark.

*Tests.*—It was not possible to make a load test at the maker's works, for sufficient power was not available. Particulars of the no-load tests are given on page 126.

The full-load test was made after the machine had been delivered to the works of Messrs. Summerson, Ltd., Darlington. Characteristic figures of the test are given on page 126. It will be seen that when running light there is a dissymmetry in the power taken by different phases: this is due to the arrangement of taps shown in Fig. 27, but does not cause any measurable interference with the voltage at the end of a long feeder. When the furnace is in circuit, the amount of load can be varied slightly by altering the distance between the electrodes. The point of maximum load is in practice found by trial. Any increase or decrease of the length of the arc from this maximum-load point causes a decrease in the load. It is sometimes convenient to vary the load by changing the length of the arc, but the steadiest conditions are obtained when the arc is on the maximum-load point. It will be seen that the balance of the load is quite good, the currents in the three lines A, B, and C being 45, 45, and 49 amperes respectively. The deviation from the perfect balance is not more than is often found on standard polyphase machines.

*Short-circuit conditions.*—A very interesting experiment is to screw down the top carbon until it dips into the metal in the furnace. As the arc is shortened, the voltage falls; when the carbon is in contact with the metal the voltage cannot be read on the voltmeter and the watts fall to a small amount of the order of 75 kw., depending upon the condition of the charge. The current rises to somewhere between 3,500 and 3,800 amperes. The load on the three-phase side falls to about 121 kw. This is satisfactory from the power company's point of view.

The author wishes to express his thanks to the Snyder Electric Furnace Company for permission to publish the figures given in the paper, to Messrs. Sandycroft, Ltd., for supplying data of the balancer, and to Mr. J. A. Kuyser for the values of the voltage drop in each phase of a three-phase generator, given below.

## APPENDIX I.

### Single-phase Load on Three-phase Generator.

The following figures were obtained from a test on an 8,000-k.v.a. star-connected three-phase generator, which was loaded up on another generator running as a synchronous motor so that the power factor of the load could be adjusted to zero. Measurements were made of the voltage on each leg of the star from the terminals to the star point, as well as between the terminals. The phases will be lettered A, B, and C in order of rotation. A single-phase load of 700 amperes at zero power factor was thrown upon terminals B and C. The voltages then were:

| | A | B | C |
|---|---|---|---|
| Phase voltage .. | 4,130 | 3,950 | 3,820 |
| | A-B | B-C | C-A |
| Terminal voltage .. | 7,150 | 6,600 | 6,950 |

It is very commonly found on three-phase machines that the phase voltages are increased by higher harmonics, so that if a diagram is made with the three phase voltages as vectors radiating from a point, and with the three terminal voltages forming the sides of a triangle, the centre point of the star forms the apex of a low tetrahedron, the altitude of the apex depending upon the amplitude of the harmonics. Notably when the phase voltage contains a pronounced third harmonic, which is absent on the terminal voltage, the altitude of the pyramid will be considerable. In this machine each phase winding was short-chorded by 60°, so that it occupied a virtual coil-width of 120°. This had the effect of eliminating the third and ninth harmonics in the phase E.M.F. wave. The winding factor of the fifth harmonic was only about 0·165, and that of the seventh harmonic 0·118.* The excess of higher harmonics in the wave-form of the phase voltage over those in the terminal voltage appears to have been of very small value, because we find, when we set out the vector diagram with the voltages given above, that the apex of the pyramid has such a small altitude that the diagram may be

* S. P. Smith and R. H. Boulding: *Journal I.E.E.*, 1915, vol. 53, p. 205.

regarded for practical purposes as lying in a plane (see Fig. 28). This clock diagram is supposed to revolve in an anti-clockwise direction, and the senses of the

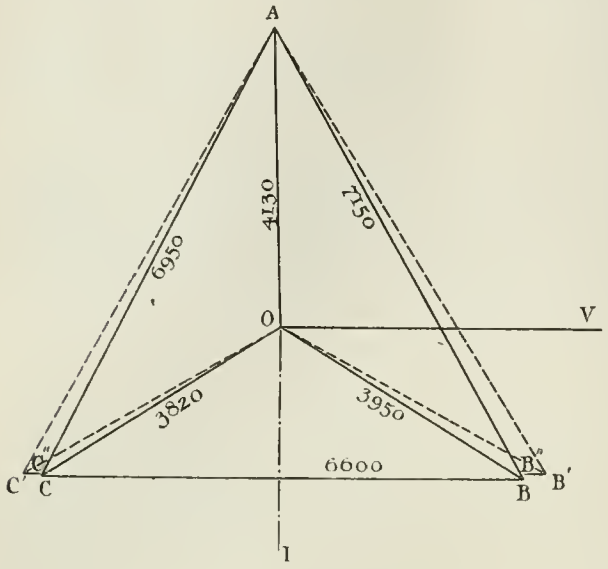



Fig. 28.

vectors must be taken with reference to Fig. 29, in which the arrow-heads show the directions taken as positive in each wire. Particular regard must be had to the direction of the current taken as positive through the single-phase load D. The vectors representing the voltages B and C are only 116° apart. The values of the voltages, and the angle between them, seem to be sufficiently well accounted for by the ordinary theory of voltage drop in generator windings. The true reactive drop in the winding appears to have been about 7 per cent of the terminal voltage. This figure agrees very well with the value obtained by the short-circuit test on the same generator. The resistance

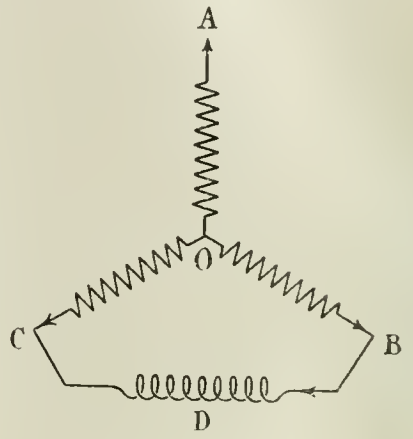



Fig. 29.

drop was only 0·375 of 1 per cent, and is almost negligible.

In Fig. 28 the author has set out the terminal voltage of B–C as the radiating vector O V, and the current of 700 amperes as the vector O I lagging 90°. If we now assume that at no load the voltage in phase B was 4,130 and occupied position O B′, making an angle of 120° with O A, and that the phase voltage in C was also 4,130 volts and occupied position O C′, also at 120° from O A, we see that the allowance of an inductive drop of 7 per cent in windings B and C, as

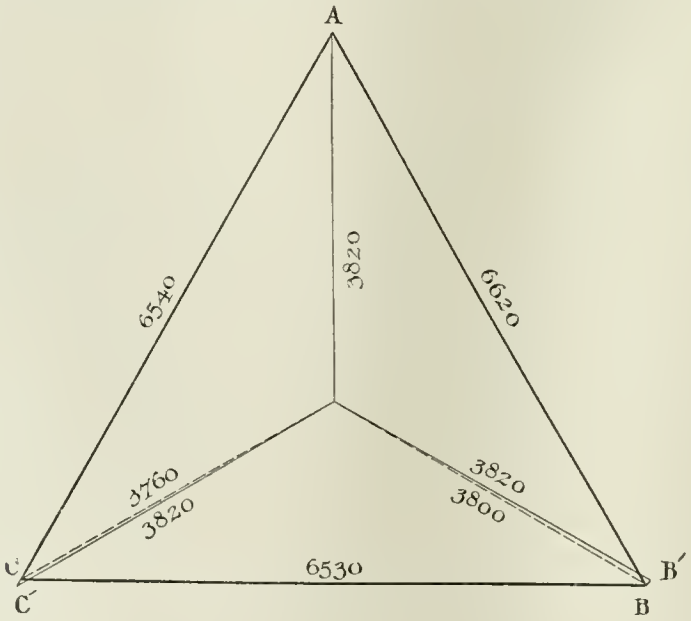



Fig. 30.

shown by the vectors B′ B″ and C′ C″, brings us almost exactly on B and C, as ascertained by actual measurements.

It will be noticed that the vector C′ C″ is taken in the sense opposite to that of B′ B″; this is because the current O I is drawn on the convention that the arrow-head on O C (Fig. 29) is the positive direction along that wire. If then we are to draw the vector C′ C″ on the convention that the arrow-head on O C is the positive direction along the circuit, it must be set out in the sense shown in Fig. 28.

From the fact that the construction shown in Fig. 28 gives us so very nearly the figures obtained on test, we can apply a similar construction for obtaining the displacement of voltage caused by a single-phase load, which forms a small proportion of the full-load rating of the machine, and at power factors higher than zero. If, for instance, we put upon the 8,000-k.v.a. 6,600-volt generator a load of only 140 amperes at a power factor of 0·7, we obtain a clock diagram (as shown in Fig. 30) in which the disturbances in the voltages of the system are as indicated in the following table:

| | A | B | C |
|---|---|---|---|
| Phase voltage .. | 3,820 | 3,800 | 3,760 |
| | A-B | B-C | C-A |
| Terminal voltage .. | 6,620 | 6,530 | 6,540 |

We see from this that where a single-phase load forms only a small part (say not more than 20 per cent) of the total load on a three-phase station, it may be thrown directly upon one of the phases of a three-phase generator without causing a serious want of balance on the three-phase system. An instance of this kind is found at Bradford, where single-phase furnaces of 400-kw. capacity are thrown on and off polyphase mains without causing a noticeable unbalancing of the voltages.

*Single-phase armature reaction.*—The ratio of the field amperes on three-phase short-circuit (700 amperes per phase) to the field amperes on no load was 0·705 on the 8,000-k.v.a. generator referred to above. When the single-phase short-circuit current of 700 amperes was put upon phase B–C, the ratio of the field amperes on single-phase short-circuit to the field amperes at no load was 0·46. It is generally found that the field ampere-turns on single-phase short-circuit are from 0·65 to 0·75 of the field ampere-turns on three-phase short-circuit, for the same armature current per phase. The exact value of this ratio depends upon the width of the pole arc and upon the efficiency of the amortisseur. Machines having a cylindrical field magnet distributed according to the ordinary plan, and having a very effective amortisseur, have a ratio in the neighbourhood of 0·65.

## APPENDIX II.

### Elimination of the Single-phase Power Component without Obtaining a Balance of Phases.

Let the current in the lines A, B, and C be

$$i_a = 100 \sin \omega t,$$
$$i_b = 75{\cdot}4 \sin (\omega t - 115°),$$
$$i_c = 96{\cdot}6 \sin (\omega t - 225°). \quad \text{(See Fig. 31.)}$$

The three vectors representing these currents form the sides of a triangle with the arrow-heads shown in Fig. 32 running concurrently. This is therefore a

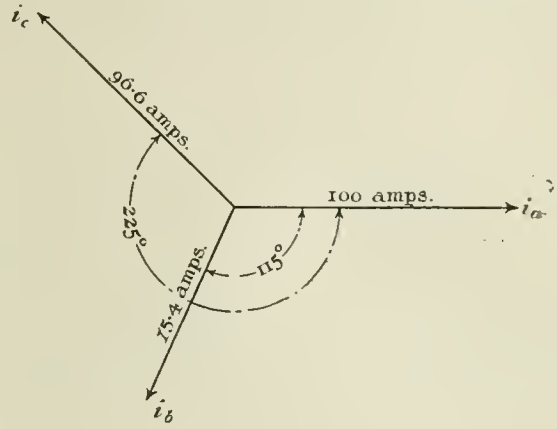



Fig. 31.

possible current distribution in a star-connected system Now let the voltages in the three legs be

$$e_a = 100 \sin \omega t,$$
$$e_b = 206{\cdot}2 \sin (\omega t - 115°),$$
$$e_c = 123{\cdot}3 \sin (\omega t - 225°).$$

Multiplying out $e_a i_a$, $e_b i_b$, and $e_c i_c$, we find that the alternating components of the power come out:

$$5{,}000 \cos 2\omega t,$$
$$7{,}780 \cos (2\omega t - 230°),$$
and $$5{,}960 \cos (2\omega t - 450°), \text{ or } 5{,}960 \cos (2\omega t - 90°).$$

The three vectors representing these alternating components form the sides of a triangle with the arrow-heads shown in Fig. 2 following concurrently. Their vector sum is therefore zero; that is to say,

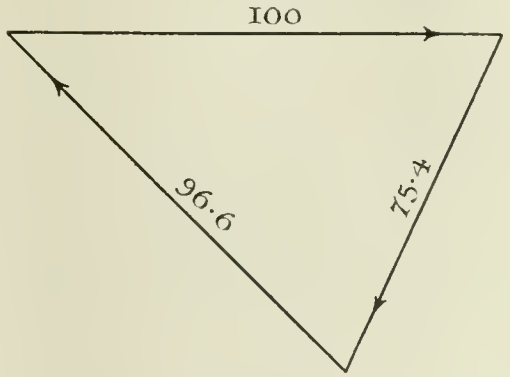



Fig. 32.

the load on the system is balanced according to Steinmetz's definition of balance, although the conditions (1) and (3) mentioned on page 111 are far from being met. We thus see that the definitions of balance given in pages 111 and 112 are not necessarily the same. If a system complies with conditions (1), (2) (3), and

(4), then it will be balanced according to Steinmetz's definition; that is to say, the sum of all the alternating components of the power is zero. But it does not follow that if the sum of all the alternating components of power is equal to zero the conditions (1), (2), (3), and (4) are also met.

## APPENDIX III.

### Graphic Construction showing Balance of Power and Balance of Phases by Means of a Choke-coil.

Let the three-phase system A, B, C, Fig. 33, be loaded * with a resistance and choke-coil between the terminals A—B. Let the voltages in A, B, and C respectively be represented by the vectors $E_a$, $E_b$, and $E_c$ in Fig. 34. Taking $e_a = E \sin \omega t$, we have

$$e_{ab} = \sqrt{3}\, E \sin (\omega t + \pi/6).$$

First let us take the instance quoted by Steinmetz † where the power factor of the current A B is such that the current lags $\pi/6 = \phi$ behind the voltage, so that

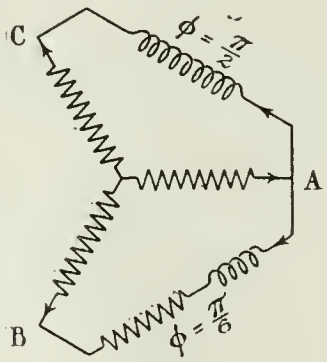



Fig. 33.

$i_{ab} = I \sin \omega t$. The alternating component of the power will be:

$$\tfrac{1}{2}\sqrt{3}\, E\, I \cos (2\omega t + \tfrac{1}{3}\pi - \pi/6),$$
$$= \tfrac{1}{2}\sqrt{3}\, E\, I \cos (2\omega t + \pi/6).$$

In order to neutralize this alternating component, we can put in circuit a choke-coil fed by a voltage

$$e' = \sqrt{3}\, E' \sin (\omega t + \pi/6 - \beta) = \sqrt{3}\, E \sin (\omega t - \pi/6)$$

where $\beta = \frac{1}{2}\phi + \frac{1}{4}\pi = \pi/12 + \frac{1}{4}\pi = \frac{1}{3}\pi$.

This voltage can be obtained from the terminals A-C, as is shown in Fig. 33, lagging 30° behind $E_a$.

The current through the choke coil is

$$i' = I' \sin (\omega t - \pi/6 - \tfrac{1}{2}\pi),$$

and if the reactance of the coil be suitably adjusted so that $I' = I$, then the alternating component of the power in the choke circuit is

$$e'\, i' = \tfrac{1}{2}\sqrt{3}\, E'\, I' \cos (2\omega t - \tfrac{1}{3}\pi - \tfrac{1}{2}\pi),$$

and as $\cos (2\omega t - 5\pi/6) = -\cos (2\omega t + \pi/6)$ the two alternating components neutralize one another. Now in this special case it will be seen from Figs. 33 and 34, taking the direction shown by the arrow-heads as positive in each leg, that before the choke-coil was added the current in leg A was $I_{ab}$, and in leg B it was $I_{ba}$. After the choke-coil is put in circuit the current

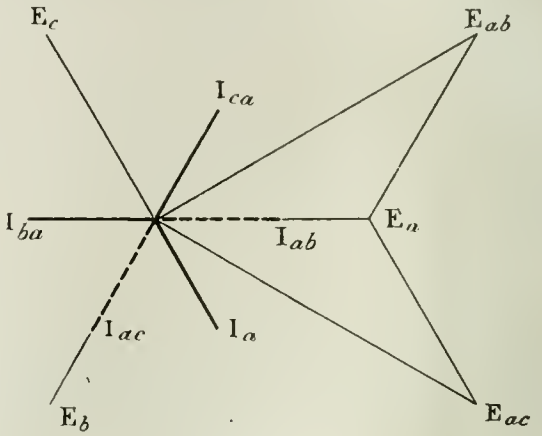



Fig. 34.

through it is $I_{ac}$ in leg A, and $I_{ca}$ in leg C. Adding together $I_{ab}$ and $I_{ac}$, we get $I_a$ as the current in A. Thus we see that the three legs carry equal currents at 120° apart; and as the voltages were assumed in balance we see that conditions (1), (2), (3), and (4) hold.

## APPENDIX IV.

### Choke-coil Balancer giving Balance of Power without Balance of Phases.

In applying Steinmetz's method to the case of single-phase load, power factor 0·7, the question whether or not we get balanced currents depends upon the way in which we build up the voltage $E' \sin (\omega t - \beta)$ from the components selected from the three phases. Let the voltages in the three legs of the star be:

$$e_a = 1{,}000 \sin \omega t,$$
$$e_b = 1{,}000 \sin (\omega t - 120°),$$
$$e_c = 1{,}000 \sin (\omega t - 240°).*$$

These are shown in Fig. 35 by the vectors $E_a$, $E_b$, and

* The example given here is the one given by Steinmetz (*ibid.*, page 326). The author shows in Fig. 34 how in this *particular instance* the phases are balanced. In Appendices II and IV examples are given in which the phases are not balanced, although the single-phase load is on the whole eliminated.

† *Ibid.*, p. 327.

* The expression of angles of lag in degrees instead of in radians is adopted for general convenience in what follows. The maximum voltage is arbitrarily taken as 1,000 so as to get four significant figures without a decimal point.

$E_c$ respectively. Let the single-phase load be fed from terminals A and C.

$e_{ac}=1{,}732 \sin(\omega t-30°)$ (see vector $E_{ac}$),
$i_{ac}=1{,}000 \sin(\omega t-30°-45°)$ (see vector $I_S$).

preserve their ratio of transformation and take their proper load, it is necessary (with this method) to carry a fourth wire to the star point of the generator; because the vector sum of the three currents is not equal to zero. If we put in circuit with these second-

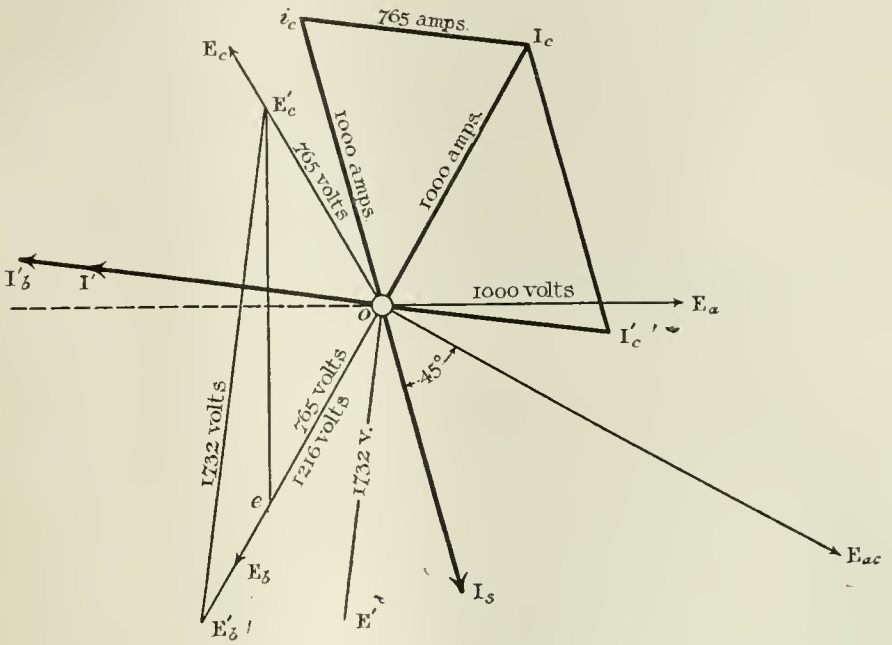



Fig. 35.

As the arrow-head indicating the positive way through the single-phase load is opposite in sense to the arrow-head on phase C (Fig. 8), the vector O $I_S$ must be reversed (see O $i_c$) to represent the current in phase C.

The alternating component of the power is

$$-\tfrac{1}{2}\times 1{,}732{,}000 \cos(2\omega t-60°-45°).$$

In order to neutralize this alternating component by means of a reactive load, we must make

$$\beta=\tfrac{1}{2}\phi+\tfrac{1}{4}\pi=22{\cdot}5°+45°=67{\cdot}5°.$$

Take $e'=1{,}732 \sin(\omega t-30°-67{\cdot}5°)$ (see vector $E_c E'_b$),
$i'=1{,}000 \sin(\omega t-30°-67{\cdot}5°-90°)$ (see vector I').

There are many different ways in which we can produce the voltage $e'$. First let us take two transformers, one having a ratio of 1,000 to 765 connected across $e_c$, and another having a ratio of 1,000 to 1,216 connected across $e_b$. If the secondaries of these are connected so as to give the resultant

$$\frac{1{,}216}{1{,}000}e_b-\frac{765}{1{,}000}e_c,$$

we shall get the vector $E'_c E'_b$ of right phase and right amplitude. In order that these transformers may

aries a reactive coil of negligible resistance having a reactance of 1·732 ohms, so that it takes the current

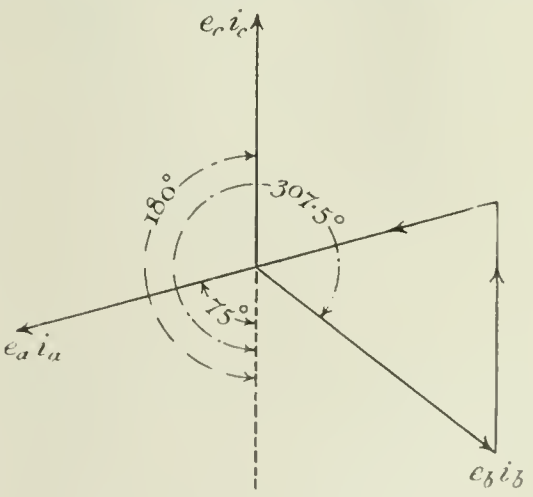



Fig. 36.

I' having a maximum of 1,000 amperes, it will be found that the alternating components of the power will balance out. When 1,000 amperes flow through

the secondary in phase C, the current in the primary will be 765 (shown by the vector O $I_c'$); and the current in the primary of phase B will be 1,216 amperes (shown by the vector O $I_b'$). The vector representing the current of the original single-phase current in phase C is O $i_c$. To this add $I_c'$, and obtain O $I_c$, the total current in C. We now see that the three currents $I_S$, $I_b'$, and $I_c$ are unbalanced and do not form a closed triangle, so that they cannot flow without the assistance of a fourth wire. Their values are:

$$i_a = 1{,}000 \sin(\omega t - 75°),$$
$$i_b = 1{,}216 \sin(\omega t - 120° - 67{\cdot}5°),$$
$$i_c = 1{,}000 \sin(\omega t - 240° - 60°).$$

Nevertheless the alternating components of the power taken in all phases balance one another out. This is seen from Fig. 36, which is a clock diagram of the double-frequency vectors obtained by taking the alternating components of the products $e_a i_a$, $e_b i_b$, and $e_c i_c$. These are:

$$\tfrac{1}{2} \times 1{,}000{,}000 \cos(2\omega t - 75°),$$
$$\tfrac{1}{2} \times 1{,}216{,}000 \cos(2\omega t - 240° - 67{\cdot}5°),$$
and $$\tfrac{1}{2} \times 1{,}000{,}000 \cos(2\omega t - 480° - 60°).$$

These form a closed triangle, notwithstanding the fact that the currents are unbalanced.

## APPENDIX V.

### Method of Choosing the Component Voltages from the Three Phases in Order to Build up $E' \sin(\omega t - \beta)$ so as to Get Balanced Currents in the Case of a Choke-coil Balancer.

The triangle $I_b' O I_c$ (Fig. 37) is intended to be the triangle whose sides shall represent the final resultant currents in phases A, B, and C. The base $I_b' O$ is necessarily parallel to I′ and lags 7·5° behind the vector O $E_a$. The vector O $I_c$ is made up of O $i_c$, which is known, and $i_c I_c$, whose direction is known, namely that of O $I_c'$, the current in the primary of the transformer in leg C. The current in the primary of the transformer in leg B is $I_b' O$. The current in A is $I_c I_b'$, which is made up of the single-phase current $I_S$ plus the transformer primary current $I_c' I_b'$; and in order that the triangle of currents shall be closed, $I_b' O$ must be greater than $I_c' O$ by an amount $I_b' I_c'$, which shall be just equal and opposite to the current in the primary of the transformer in leg A, namely $I_c' I_b'$. Now the currents in the primaries of the transformers are directly proportional to the number of turns in the secondaries. Therefore the number of turns in the secondary of B shall exceed that of C by a number which shall be equal to the number of turns in the secondary of A. We therefore necessarily have two isosceles triangles,

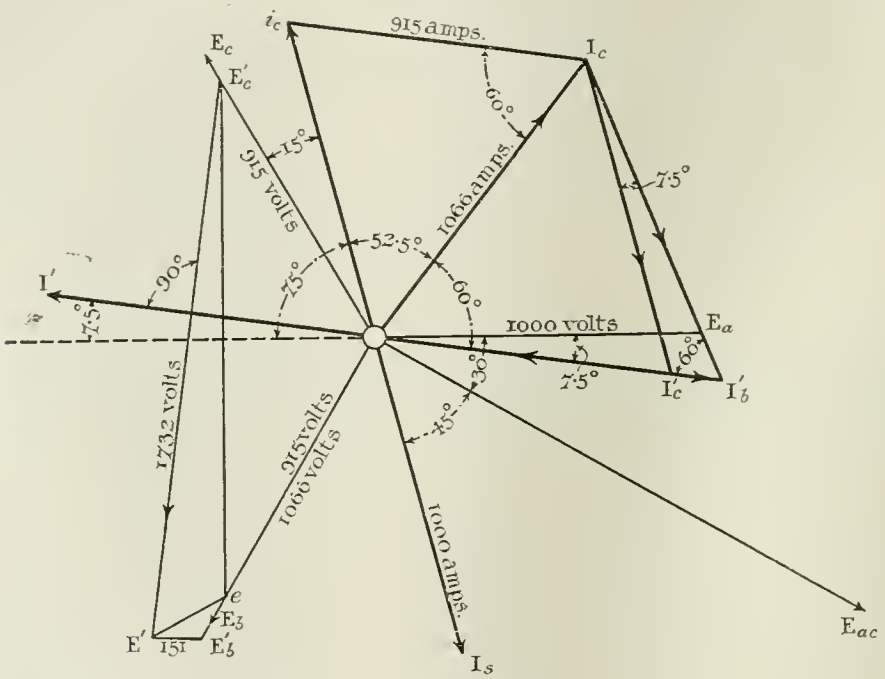



Fig. 37.

$O\,e\,E_c'$ and $E_b'\,E_e'$, built up by the voltage vectors having the sides $O\,E_c'=O\,e$ and $E_b'\,e=E_b'\,E'$. The number of turns in the secondaries of the transformers (taking the primaries as 1,000) is most easily determined by taking the ratio of the sines of the angles in the triangles $I_c\,I_c'\,I_b'$ and $O\,i_c\,I_c$, as follows:

$$\frac{I_c'\,I_b'}{I_c'\,I_c}=\frac{\sin 7{\cdot}5^\circ}{\sin 60^\circ}=0{\cdot}151,$$
$$\frac{i_c\,I_c}{i_c\,O}=\frac{\sin 52{\cdot}5^\circ}{\sin 60^\circ}=0{\cdot}915,$$
$$I_b'\,O=0{\cdot}151+0{\cdot}915=1{\cdot}066.$$

Therefore the turns in the secondaries of A, B, and C, are 151, 1,066, and 915 respectively. With 1,000 volts on each of the three primaries of 1,000 turns we get:

$$E_c'\,O=\ 915 \text{ volts}$$
$$O\,E_b'=1{,}066\ \ ,,$$
$$E_b'\,E'=\ 151\ \ ,,$$

and the vector sum of these is $E_c'\,E'=1{,}732$ volts, which gives us the voltage $e'$ in the correct phase. If

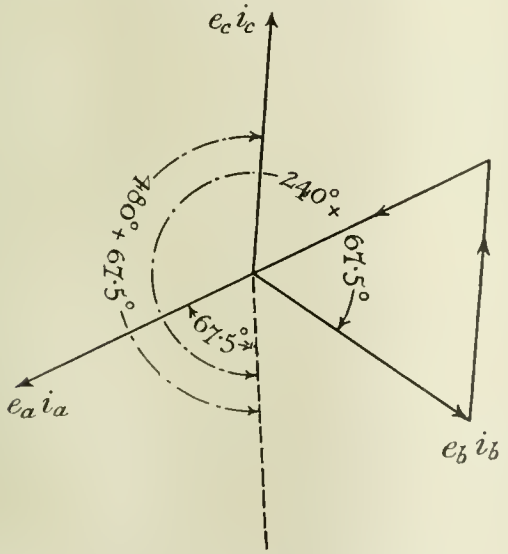



Fig. 38.

now we put in circuit with this a reactance of 1·732 ohms we get 1,000 amperes lagging 90° flowing in the secondaries, and this calls for currents in the primaries of the same phase (assuming perfect transformers) the amounts of which are:

Phase A 151 amperes
,, B 1,066 ,,
,, C 915 ,,

If now we add the 1,000 amperes $I_S$ in phase A to $I_c'\,I_b'$, we get 1,066 amperes total in phase A; and if we add the 1,000 amperes $O\,i_c$ to $i_c\,I_c$ we get $O\,I_c=1{,}066$, so that all three currents are equal and at 120° to one another. The angle of lag of each current behind its E.M.F. is 67·5° in each case. The alternating components of the power in the three circuits are equal, and the double-frequency vectors representing them are at 120° to one another. They therefore cancel out (see Fig. 38).

## APPENDIX VI.

### Method of Choosing the Component Voltages from the Three Phases in Order to Build up E′ Sin $(\omega t-\beta)$, so as to Get Balanced Current in the Case of a Condenser Balancer.

In this case $\beta=\frac{1}{2}\phi-\frac{1}{4}\pi=-22{\cdot}5^\circ$; therefore $-\beta=+22{\cdot}5^\circ$; so that in laying out O E′ in Fig. 40 we set off the angle at 22·5° from O $E_{ac}$ anti-clockwise. The problem is to build up this voltage, O E′, from the three-phase voltages $E_a$, $E_b$, and $E_c$. The scheme of connections is shown in Fig. 39. The condenser is fed from three secondaries connected in series, each secondary being wound on a separate core the primary of which is supplied from one of the three phases A, B, and C respectively. It is assumed that there are 1,000 turns on each of the primaries; the problem is to find the number of turns on the secondaries so as to get the desired result.

The condenser current I′ (Fig. 40) is 90° ahead of E′, and is taken as 100 amperes, 100 amperes being taken as the current on the single-phase furnace $I_S$. The value of the current in any one of the primaries of the transformers will be directly proportional to the number of turns of its secondary. It will be seen that the only current in phase B will be the current fed to the primary of transformer B (neglecting the magnetizing current); it will be in phase with I′.

As we are aiming at having the resultant currents in phases A, B, and C at 120° to one another, these currents must form the sides of an equilateral triangle such as that drawn in double lines in Fig. 40. The phase of the base of this triangle is given by the phase of I′; and it will be further seen that the resultant A must be obtained by adding together the vector $O\,I_S$ and another vector parallel to O I′; similarly, the resultant C must be obtained by adding together the vector $O-I_S$ and another vector parallel to I′ O. Thus the height of the equilateral triangle is determined by setting off a line $I_S\,I_A$ parallel to O I′ and finding the point where it intersects the line $O\,I_A$, which is necessarily at 60° to O I′. The equilateral triangle is then completed by drawing the resultant C, which is necessarily equal to $O\,I_C$ obtained by drawing a vector $-I_S\,I_C$ parallel to I′ O. If we now scale off the currents $I_S\,I_A$, $O\,I_B$, and $-I_S\,I_C$, we find that these are 114·2, 44·7, and 70 amperes respectively;

therefore the number of turns in the secondaries of the transformers should be 1,142, 442, and 700 respectively. If we now set off three voltage vectors 1,142, 70, and 442 volts respectively, parallel to $E_a$, $-E_c$, and $E_b$ respectively, we obtain the vector O E′ representing 1,732 volts, 22·5° ahead in phase of $E_{ac}$.




Fig. 39.

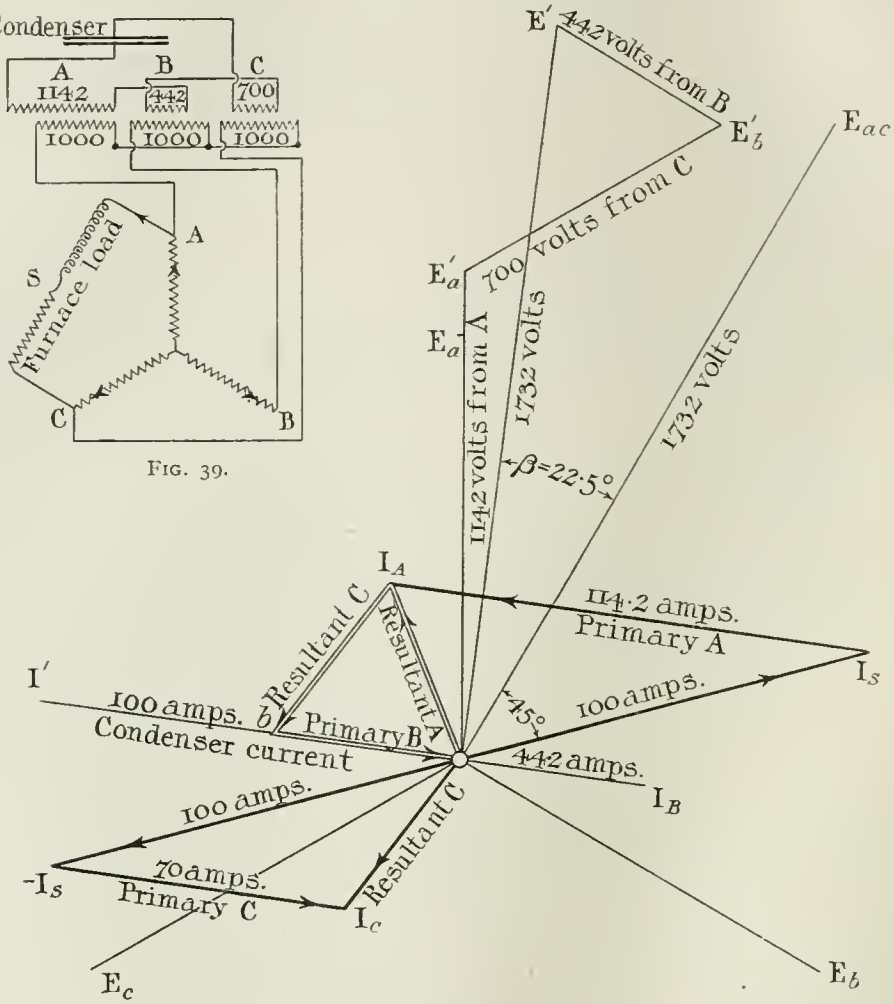



Fig. 40.

## APPENDIX VII.

### Calculation of Dimensions of the Machine.

*Size of frame and speed.*—It was decided to use an 8-pole frame so as to get a speed of 750 r.p.m. Since single-phase machines require bigger frames than three-phase, a $D^2 l$ constant of $6 \times 10^6$ suggested a frame with an internal bore of 91·5 cm. and length of iron of about 42 cm. The makers had a frame of size 140 cm. (outside stator punchings), and as these figures appeared convenient they were decided upon.

The general method of calculation is that described by the author in his book "The Specification and Design of Dynamo-electric Machinery." In order to shorten this paper, the author will rely upon the descriptions and explanations of the general method given in the book. The calculation sheet reproduced on page 124 is the same as that used throughout the book, see pages 317 to 320. Matters that are rather special to this machine will be given somewhat more fully. All dimensions are given in centimetres.

*Three-phase winding.*—Allowing for impedance drop in the winding, the generated back E.M.F. should be about 6,000 − 60 = 5,940 volts. As the frame would carry a total $A_g B$ of about $1 \times 10^8$, an approximate number of conductors would be 1,200. For 8 poles 1,152 (= 72 slots × 16 conductors per slot) is a convenient number. The E.M.F. coefficient $K_e = 0{\cdot}4$ (see page 23 of book). Revolutions per second = 12·5. We thus arrive at the voltage formula

$$5{,}940 = 0{\cdot}4 \times 12{\cdot}5 \times 1{,}152 \times 1{\cdot}03.$$

*Size of three-phase conductors.*—Allowing an efficiency of 90 per cent, we have 444 kw. input at unity power factor. This gives us 43 amperes per phase, or, allowing a little margin for power-factor adjustment, say 47 amperes per phase.

The size of conductor chosen was $0{\cdot}26 \times 0{\cdot}5$ (0·127 sq. cm. in area, allowing for rounded corners). This gives 370 amperes per square centimetre at 47 amperes. The 16 conductors are arranged in two rows of 8, with substantial insulation between them.

In addition to the room taken up by 16 conductors per slot, room is left for 3 compensating conductors, the function of which is described on page 123. These conductors were made $0{\cdot}13 \times 1$, as they had not to be bent edgewise. The size of slot required was 1·7 cm. wide × 3·7 cm. deep. Particulars of the lengths and resistance are given in the calculation sheet.

*Single-phase winding.*—The single-phase winding is placed in 48 slots at the back of the 48 slots occupied by phases A and C. No single-phase slots are punched behind the slots occupied by phase B. The shape of the punchings will be seen in Fig. 21. Since a current of 2,750 amperes would require a very large conductor, and since the single-phase voltage to be generated is very low, it is obviously the best plan to put 8 paths in parallel, each of which can contribute 2,750/8 amperes. This gives us 340 amperes per conductor, and at 50 cycles we should still be troubled with eddy currents if we did not split up the conductor for this current. The actual conductor chosen consists of 3 square wires in parallel. Each wire is 0·6 cm. wide (0·35 sq. cm. in area). These individual wires are crossed over in the course of connecting up, so that each wire embraces exactly the same leakage flux, and no eddy currents flow between the three in parallel. The eddy currents in the individual wires lying in the slots, calculated by Field's curves, give a mean loss 22 per cent higher than the $I^2R$ loss for direct current.

The number of turns required in the single-phase winding to give 234 volts at no load can be calculated as in an ordinary transformer, so long as all wires are symmetrically placed with respect to the wires in the three-phase slots of phases A and C, and have the same winding factor. In 48 slots we have $48 \times 16 = 768$ conductors. $768 \times 234 \div 6{,}000 = 30$ conductors in 6 slots (15 turns per pole), or 5 conductors per single-phase slot. Had it been necessary to get 247 volts at no load, some of the three-phase conductors would have been cut out to increase the working flux by 5 per cent. Before the winding was completed, however, the makers of the furnace decided that they would not require more than 220 volts at no load, the relations between the various voltages on load being as indicated in Fig. 22. It was therefore necessary to cut out one of the 15 turns per pole of the single-phase winding; and the question arose whether it should be a turn embracing 4 teeth or a turn embracing 8 teeth. To determine this, it is only necessary to calculate the winding factors* for the various single-phase coils and the winding factor for the three-phase winding in the 6 slots occupied by phases A and C.

* See Smith and Boulding: *Journal I.E.E.*, 1915, vol. 53, p. 215.

There being 9 slots per pole, the slot pitch is (electrically) 20°. None of the coils of the single-phase winding is of really full pitch. The largest coil, embracing 8 teeth, is short of full pitch by 20°; the second, by 60°; and the smallest coil, by 100°. Taking the winding factor of a really full-pitch coil to be unity, we have:

| Coil | Cosine of Half-angle of Phase-difference of Coil Sides | Winding Factor |
|---|---|---|
| Longest .. | .. cos 10° | 0·9848 |
| Middle .. | .. cos 30° | 0·866 |
| Smallest .. | .. cos 50° | 0·6428 |
| | | 3)2·4936 |
| | Mean .. .. | 0·831 |

The mean winding factor can also be found by the formula given * by Smith and Boulding for coils lying in slots, namely:

$$\frac{\sin \frac{1}{2} m\gamma}{m \sin \frac{1}{2}\gamma} = \frac{\sin 6 \times \frac{1}{2}(20°)}{6 \sin \frac{1}{2}(20°)} = \frac{\sin 60°}{6 \sin 10°} = 0{\cdot}831.$$

Now this winding factor, 0·831, applies to the three-phase winding. Therefore, when we have 5,940 volts (virtual) generated in the 768 conductors between the terminals A and C, the volts per conductors generated are really:

$$\frac{5{,}940}{768} \times \frac{1}{0{\cdot}831} = 9{\cdot}3 \text{ volts (virtual).}$$

We can arrive at the voltage generated by the 10 conductors making up each coil, as follows:

| | | |
|---|---|---|
| Large coil .. | $9{\cdot}3 \times 0{\cdot}9848 \times 10 = 91{\cdot}7$ | volts |
| Middle .. | $9{\cdot}3 \times 0{\cdot}866 \times 10 = 80{\cdot}5$ | ,, |
| Smallest .. | $9{\cdot}3 \times 0{\cdot}6428 \times 10 = 59{\cdot}8$ | ,, |
| | 232 | volts for 15 turns |

If now we have only 4 turns (instead of 5) in the smallest coil, we get the figures as follows:

| | | |
|---|---|---|
| Large coil .. | $9{\cdot}17 \times 10 = 91{\cdot}7$ | volts |
| Middle .. | $8{\cdot}05 \times 10 = 80{\cdot}5$ | ,, |
| Smallest .. | $5{\cdot}98 \times 8 = 47{\cdot}8$ | ,, |
| | 220 | volts nearly, for 14 turns |

*Calculation of permeance of path for leakage flux and single-phase winding.*—The amount of the reactive drop in the electric furnace and connections was not exactly known when the machine was first laid out. In order, therefore, to allow a margin for adjustment, the three-phase winding was arranged so that there might be either 15 wires per slot or 16 wires per slot, and the single-phase winding so that there might be 15 turns per pole, or any smaller number. With 15 wires per slot (instead of 16) in the three-phase winding, and 15 turns per pole in the single-phase winding, the open-circuit low-tension voltage would be $232 \times 16/15 = 247$. Even if the inductive drop in the furnace came out as high as 50 volts, it would still be possible to get the required output into the furnace

* *Loc. cit.*

at this voltage by making the inductive drop in the single-phase winding about 140 volts. The total inductive drop would then be about 190, and if the resistance drop were 156 the right-angled triangle (see Fig. 41) would be sufficiently well shaped for stable operation. If, however, the inductive drop in the furnace came out lower, the open-circuit voltage could be lowered either by using less than 15 turns on the secondary or by increasing the wires in the three-phase slots. These two expedients are somewhat different in their final effect. A reduction of the number of turns in the secondary is accompanied by a very considerable reduction in the inductance of the secondary winding, while an increase of the three-phase conductors has very little effect upon the inductance. The depth and width of the air-gap in the leakage path between primary and secondary (see Fig. 21) were adjusted to give about 140 volts inductive drop in the single-phase winding when the latter was carrying 340 virtual amperes in the 15 turns per pole.

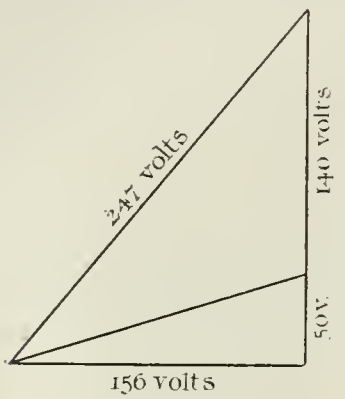



Fig. 41.

The main path for the leakage flux around the single-phase winding is that across the narrow slit (0·45 cm. wide) that has been provided for this purpose between the long teeth. The radial length of the slit and its width were determined by some such calculation as that given below, which takes into account the amount of leakage occurring across the three-phase slot, the single-phase slot, etc. All that was necessary was to see that the radial depth (4·7 cm.) was great enough to carry the balance of the leakage flux required. The following is the final calculation.

*Permeance (per cm. length of iron) of the leakage path for flux produced by single-phase winding (see page 422 of author's book for explanation of the method of calculation).*

Body of three-phase slot $3\cdot7 \div 1\cdot7$ .. .. $= 2\cdot2$
Mouth of slot .. .. .. .. $= 1\cdot1$
Zigzag $0\cdot34 \times \frac{4}{2} \times \frac{1}{2 \times 0\cdot55 \times 1\cdot1}$ .. $= 0\cdot56$
Leakage air-gap $4\cdot7 \div 0\cdot45$ .. .. $= 10\cdot4$
Compensating conductor space $1\cdot1 \div 1\cdot8$ $= 0\cdot61$
Single-phase slot $\frac{1}{3} \times \frac{3\cdot8}{2\cdot3}$ .. .. $= \frac{0\cdot55}{15\cdot42}$

Twice the length of iron .. .. $= 42 \times 2 = 84$ cm.
M.M.F. per slot $= 340 \times 5 \times 1\cdot41 \times 1\cdot257 = 3{,}020$

$15\cdot42 \times 84 \times 3{,}020$ .. .. $= 3\cdot92 \times 10^6$
End leakage .. .. .. $= 0\cdot4 \times 10^6$
Leakage lines per pole .. $= 4\cdot32 \times 10^6$

As the reluctance of the magnetic path is mainly in the air-gaps considered, the leakage flux (when the 15 turns are carrying single-phase current) will encircle all 15 conductors. The voltage generated will therefore be:

Reactance volts in single-phase winding

$= 0\cdot707 \times 2\pi \times 50 \times 15 \times 4\cdot32 \times 10^{-2}$
$= 144$ volts, or $144/30 = 4\cdot8$ volts per conductor.

This is with 15 turns per pole in the single-phase winding. If we reduce the number of conductors in one of the slots from 5 to 4, we do not affect the leakage across the remaining slots, but we cut down the volts per conductor in the one slot to $4\cdot8 \times 4/5 = 3\cdot85$ per conductor. The reactance voltage for 14 turns per pole is therefore $(20 \times 4\cdot8) + (8 \times 3\cdot85)$

$$96 + 31 = 127$$

It is better to have the reactance rather too little than rather too much, because if it is too much it is impossible to get the full input, whereas if it is too little one can always reduce the input by increasing the length of the arc. We shall therefore take the figure 127 volts as near enough to 128 volts (the theoretical value given by Fig. 22) for practical purposes, and we cannot hope to predetermine the leakage flux with any great degree of accuracy.

*Taps on single-phase winding.*—It is sometimes desirable, after the metal is heated up in a refining furnace, to reduce the electrical input to such a point that the metal is maintained at an even temperature for some time. For this purpose it is usual to provide means of reducing the voltage in the furnace to less than one-half. In this case it was decided to put a tapping in each group of coils in parallel, at a point 5 turns removed from the outer terminal. These five turns will give $9\cdot17 \times 10 = 91\cdot7$ volts.

## APPENDIX VIII.

### Method of Calculating the Number of Compensating Turns.

Below is given the calculation of the flux across 1 cm. length of three-phase slot produced by unit magnetomotive force in the single-phase slot and effective in producing E.M.F. in the three-phase windings. It will be noted that the effective permeance of the body of the three-phase slot is taken at one-half the value taken above. This is for the reason that the conductors nearest the mouth of the

three-phase slot do not embrace the whole of the flux in question. The total cutting of lines may be taken approximately as one-half the flux into all the conductors. Deducting 0·3 cm. for the insulation space at the top of the slot, the effective depth of slot is 3·4 cm.

| | |
|---|---|
| Half body of three-phase slot $\frac{1}{2}\times(3\cdot4\div1\cdot7)$ | $=1\cdot0$ |
| Mouth of slot .. .. .. | $=1\cdot1$ |
| To rotor and back despite damper .. | $=0\cdot56$ |
| | 2·66 |

Flux threading through compensating winding per cm. length of iron for unit M.M.F. in single-phase slot

$$=2\cdot66\times19=50\cdot5.$$

| | |
|---|---|
| Leakage air-gap .. .. .. .. | $=10\cdot4$ |
| Three-phase slot $3\cdot4\div1\cdot7$ .. .. | $=2\cdot0$ |
| Half compensating coil slot $=\frac{1}{2}(1\cdot1\div1\cdot8)$ | $=0\cdot3$ |
| | 12·7 |

From this it appeared that four compensating conductors ($4\times12\cdot7=50\cdot8$) would embrace as much leakage flux as 19 conductors in the three-phase slots. The original design provided for 15 working conductors per slot plus four compensating conductors. When, however, it was found that the reactive voltage of the furnace was only about 28 volts, it was necessary to increase the three-phase conductors to 16. This cut down the compensating conductors from 4 to 3. To make up for this deficiency, a slightly unsymmetrical connection (described above) was made in the bringing out of the connections to the star point. This had the effect of substantially balancing the phases at full load, as will be seen from the figures given on page 126.

## APPENDIX IX.

### Calculation of the Ampere-turns on the Field-magnet.

It is necessary to make a calculation of the number of ampere-turns required at full load in order to preserve unity power factor on the three-phase side.

*Single-phase armature ampere-turns.*—The power factor of the single-phase load is 0·7, so that the demagnetizing effect of the single-phase winding will be considerable The best way of estimating the single-phase reaction is to rely upon experience with previous machines. As shown above, the average magnetizing effect of a single-phase load may be taken as from 0·65 to 0·75 of the magnetizing effect of a load of the same current per phase on all three phases. On this machine we have a very effective damper, and may take the effect of the single-phase load as equivalent to about 0·7 of the corresponding three-phase load. In the low-tension winding we have 14/3 conductors per slot. The current per conductor is 340 amperes. The single-phase ampere-turns may therefore be taken as

$$\frac{14}{3}\times\frac{72\times340\times0\cdot43\times0\cdot7}{8}=4,280 \text{ ampere-turns per pole.}$$

*Three-phase armature ampere-turns.*—With 47 amperes per phase in the three-phase winding, the ampere-turns per pole are $47\times1,152\times0\cdot43\div8=2,900$ ampere-turns per pole.

*Inductive drop in three-phase winding.*—The permeance of the armature leakage path for leakage flux generated by the three-phase current can be calculated as follows:

| | |
|---|---|
| Body of slot $\frac{1}{3}\times(3\cdot4\div1\cdot7)$ .. | $=0\cdot66$ |
| Mouth.. .. .. .. | $=1\cdot0$ |
| Zigzag .. .. .. | $=0\cdot56$ |
| | 2·22 |

Leakage flux across slots at load of 47 amperes:

| | |
|---|---|
| $2\cdot22\times42\times2\times16\times1\cdot41\times1\cdot257\times47$ | $=0\cdot25\times10^6$ |
| End leakage.. .. .. .. | $=0\cdot15\times10^6$ |
| | $0\cdot4\times10^6$ lines per pole. |

The working flux per pole $=8\cdot6\times10^6$.

Inductive drop in three-phase winding

$$=\frac{0\cdot4}{8\cdot6}\times6,000=280 \text{ volts.}$$

*Resistance drop in three-phase winding.*

| | |
|---|---|
| Resistance per phase .. | $=\frac{1}{3}(2\cdot34)=0\cdot78$ ohm. |
| $0\cdot78\times47\times1\cdot73$ .. | $=64$ volts. |

*Resultant ampere-turns*—We are now in a position to draw the vector diagram that shows the relation

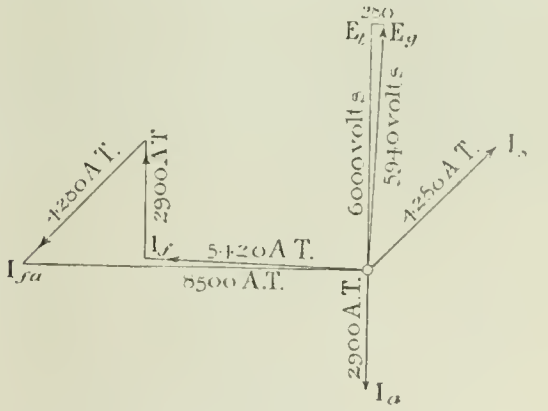



Fig. 42.

between the various magnetizing and demagnetizing ampere-turns on the field magnet and armature. This is given in Fig. 42.

The conventions used in setting out this vector diagram are the same as those employed in Fig. 300 of the author's book referred to above. It will be seen that the ampere-turns of the armature are repre-

sented by the line $I_a$, which is 180° out of phase with the terminal voltage vector $E_t$. This is due to the fact that the machine is running as a synchronous motor on unity power factor. The single-phase armature ampere-turns $I_S$ are set off at 45° behind $E_t$, because the single-phase armature is supplying a generator load at power factor 0·7. From the calculation sheet we see that 5,420 effective ampere-turns are required on the field pole to generate $E_g$=5,940 volts (obtained by setting off the impedance drop from the terminal volts $E_t$). The vector $I_f$ is set off to represent 5,420 ampere-turns to scale at right angles to $E_g$. Then, setting off $I_a$ and $I_S$ reversed we arrive at $I_{fa}$, representing 8,500 ampere-turns to be applied to the field pole to neutralize the single-phase and three-phase armature reactions and leave 5,420 effective ampere-turns to generate $E_g$. This graphic construction gives a result which agrees fairly well with the figures obtained on test. The exciting current required to give a mean power factor of unity (as will be seen later, the phases were not perfectly balanced) was 39 amperes; so that the applied field ampere-turns per pole were 39×224=8,736. The saturation of the poles may have been higher than expected, or the single-phase reaction rather more than 4,250 ampere-turns.

## APPENDIX X.

### Calculation of the Armature Copper Losses.

*Single-phase coils.*—The measured resistance of each of the 8 coils of 14 turns in the single-phase winding is 0·00442 ohm at 14° C. The crossing over of the three wires in parallel that make up the conductors of these coils had the effect of preventing any violent eddy current in the conductor as a whole; but there is still a small eddy current, owing to the fact that each wire has a depth of 0·6 cm. In the conductor lying nearest to the mouth of the slot, the eddy current, calculated from Field's curves,* gives rise to an additional loss equal to 55 per cent of the normal copper loss; so that $K_d$=1·55. The values of $K_d$ for all conductors are as follows:

$m_1$=1·0
$m_2$=1·06
$m_3$=1·17
$m_4$=1·33
$m_5$=1·55

5)6·11

1·22

so that on the whole the eddy currents only increase the normal loss in the buried copper by 22 per cent. Allowing for a rise of resistance with temperature of 20 per cent, we have the normal loss (without eddies) in the 8 coils:

$$0{\cdot}00442 \times 1{\cdot}20 \times 340 \times 340 \times 8 = 4{,}900 \text{ watts.}$$

* *Transactions of the American Institute of Electrical Engineers*, 1905, vol. 24, p. 761.

Of these, (42/92)×4,900=2,240 watts are in copper buried in the slots. This must be multiplied by 1·22 to allow for eddy currents.

$$2{,}240 \times 1{\cdot}22 = 2{,}740.$$

The losses in the copper of the end windings would be normally 2,660 watts. This is also somewhat increased by eddy-current losses, though not to the same extent as the copper in the slots. Allowing 10 per cent increase due to eddies in the end windings, we get a total loss in the single-phase winding

$$2{,}740 + 2{,}926 = 5{,}666 \text{ watts.}$$

*Three-phase winding.*—The hot resistance of the three-phase coils is 2·24 ohms. The loss for a current of 47 amperes is 4,950 watts.

*Heat dissipated from the end windings.*—The total cooling surface of the three-phase and single-phase end windings is 86,000 sq. cm. In view of the strong draught created by the blower, each square centimetre can easily get rid of 0·09 watt per sq. cm. for 30 degrees C. rise of the outside of the coils. And as the half-length of the machine is only 21 cm., one may expect quite a large percentage of the heat generated in the slots to find its way to the end windings and pass into the air along with the heat generated in the end windings.

| | |
|---|---|
| Total losses in three-phase and single-phase coils | 10,610 |
| 86,000×0·09 .. .. .. .. .. | 7,740 |
| | 2,870 |

Thus we have 2,870 watts to pass through the slot insulation to join the heat generated in the iron.

*Iron losses.*—The calculated iron loss at no load is 11,500. To this figure must be added very considerable stray losses at full load. These losses cannot be calculated, but they are estimated at 4,000 watts. Thus the total losses to be dissipated from the surfaces of the iron are about:

| | |
|---|---|
| Iron loss .. .. .. | 11,500 |
| Stray losses .. .. .. | 4,000 |
| Buried copper .. .. | 2,870 |
| | 18,370 |

The manner in which this loss can be dissipated from the surfaces of the stator for a temperature rise of 45 degrees C. is shown in the calculation given below. For further particulars of the method employed the author refers to his book (page 254).

*Heat dissipated from working face of armature.*—Peripheral speed 36 metres per second. Assuming a difference of temperature of 35 degrees C. between iron and air, we have

$$\text{Watts per sq. cm.} = \frac{35 \times (1 + 3{\cdot}6)}{333} = 0{\cdot}485.$$

12,100 sq. cm. ×0·485=5,900 watts.

*Heat dissipated by ventilating ducts.*—Taking the coefficient $K_v=0{\cdot}0007$ and the mean velocity in the ducts at 7 metres per sec., we have

$$h_v=0{\cdot}0007\times 7=0{\cdot}0049.$$

The total area of ventilating ducts, including the leakage air-gaps, is 83,600 sq. cm. Taking the mean difference in temperature between the iron and air in ducts at 20 degrees C., we have

$$0{\cdot}0049\times 20\times 83{,}600=8{,}200 \text{ watts.}$$

*Heat dissipated from outside of stator.*

$$38{,}700 \text{ sq. cm.}\times 0{\cdot}15=5{,}800.$$

*Total heat dissipated from stator for 45 degrees C. rise.*

$$5{,}900+8{,}200+5{,}800=19{,}900 \text{ watts.}$$

## SPECIFICATION OF 444-K.V.A. SYNCHRONOUS BALANCER THREE-PHASE TO SINGLE-PHASE.

6,000 volts to 240 volts.

Reactive drop, 140 volts.

50 cycles, 8 poles, 750 revs. per minute.

Amperes per terminal: three-phase, 47; single-phase, 2,750.

### Stator.

(All dimensions in centimetres.)

| | | | |
|---|---|---|---|
| Outside diameter | .. | .. | 140 |
| Inside diameter | .. | .. | 91·5 |
| Gross length .. | .. | .. | 42 |
| Air vents $6\times 0{\cdot}7=$ | .. | .. | 4·2 |
| Net length of iron | .. | .. | 34 |
| Depth below slots | .. | .. | 10 |

Stalloy iron.

72 three-phase slots each $1{\cdot}7\times 4{\cdot}1$ (see Fig. 21).

*Three-phase winding.*—16 effective conductors per slot. Room in slot for 19 conductors. Phases A and C have 19 conductors per slot, three of them forming part of compensating winding. Phase B has 16 conductors per slot. Size of conductors $0{\cdot}26\times 0{\cdot}5$. Three taps to be brought out of each phase near the star point, viz. at 3, 6 and 9 turns respectively from the star point.

*Single-phase winding*, lying in 6 slots per pole, as shown in lay-out. 5 conductors per slot, each consisting of 3 square wires in parallel. Size of wire 0·6 cm. square (=0·35 sq. cm.). 15 turns per pole, 8 poles in parallel. The 3 individual wires are to be crossed over by special connectors at the joints One tapping to be brought out of each coil.

### Field Magnets.

8 poles.

Pole-body, $16{\cdot}5\times 35$. Soft iron or very mild steel.

Pole arc, 24. Radial length of gap, 0·5.

Radius of curvature of pole face, 41·3.

Bevel extending over 3 cm., giving an air-gap at corner of 0·8.

*Field winding.*—224 ($32\times 7$ layers) turns per coil. Size of wire, $0{\cdot}35\times 0{\cdot}35$ (say, No. 10 B.W.G. square wire). Exciting current 40 amperes, 50 volts.

*Damper.*—11 bars per pole, 9 drawn taper bars about 1·3 sq. cm. section. End rings each built up in 8 sections, one section per pole, bolted together, cross-section about 7·5 sq. cm. Damper rods held in dovetail grooves machined out of pole face: these are preferably skewed over the pitch of slots.

Poles should be laminated.

## Discussion before The Institution, 5 December, 1918.

**Dr. S. P. Smith:** Only those who have tackled problems like those considered in the present paper will appreciate the amount of labour involved, but the interesting and useful solutions often obtained may well repay the investigator, and students should not be discouraged by the inherent difficulty of the subject. The author's use of vectors for solving these problems reminds me of the interesting case offered by the Greaves-Etchells two-arc furnace. The fact that it is not a single-phase furnace does not make the problem less useful for the purposes of illustration. The connections of this furnace are shown in Fig. A, and the problem considered here is to arrange the number of turns in the secondary winding of the transformer in such a manner that the load on the primary side is balanced when the resistance of the load phase formed by the hearth of the furnace is zero. At first sight it would seem that a load of this nature on the secondary side would cause the load on the primary side to be unbalanced. The vector diagram in Fig. B, however, shows that

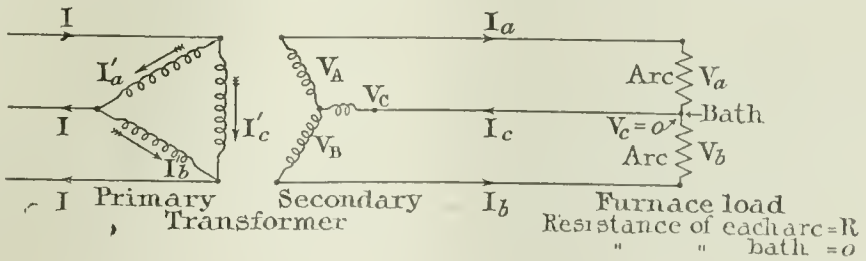



Fig. A.

a balanced load is taken from the supply when the number of turns in the secondary phase connected to the bath is equal to 36·6 per cent of the number of turns in each of the other two secondary phases. The author does well to draw careful distinction between the different methods of defining "balance"; and care should be taken when balancing problems are discussed to make it clear whether balance of phases or balance of pressures and currents is implied. There is one point which I should like to raise with regard to electric furnaces. In a two- or three-phase furnace the ammeter needles swing violently at times, especially during charging, and it seems to me that such sudden changes of load in the several phases must produce

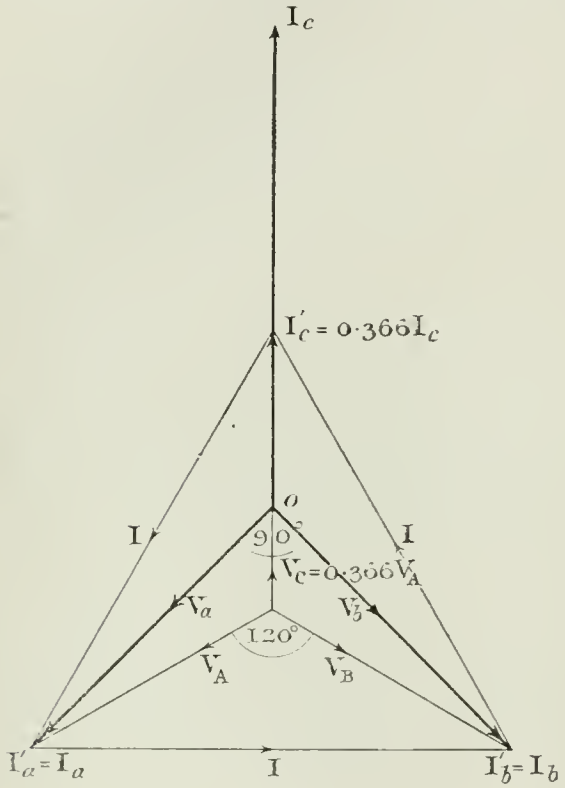



FIG. B.

rather bad instantaneous out-of-balance effects. From this point of view, the single-phase furnace with the rotary balancer described by the author would appear to compare favourably with the polyphase furnaces, but I should be very glad to hear this point discussed. There is one way in which the electric furnace appeals especially to electrical manufacturers. The difficulty experienced for many years by such firms in obtaining quick delivery of steel castings is well known. The causes of this delay and the future outlook in this respect need not be discussed here, but attention should be drawn to the fact that the electric furnace may provide a simple and satisfactory solution of the difficulty. Most electrical firms have a lot of good steel scrap from laminations, turnings, etc., and if a small single-phase furnace, say, were installed, this scrap could be melted down (I am not speaking of steel refining or smelting), and large electrical firms would then be in a position to make their own steel castings for yokes, magnets, etc., in the same way as they make at present their own iron castings.

**Mr. G. W. Partridge:** It would be very interesting to me, as a supplier of three-phase and single-phase current, if the author, in describing the different methods of balancing, would state the possibility in each case of reversing the action, that is to say, of getting three-phase current from a single-phase system. The demand for single-phase current is now so general that it becomes necessary to make adequate provision for it in all large systems of generation and distribution. With regard to the question of railway supply, the use of single-phase current for railway electrification is well known to-day, and with our present experience it is impossible to say to what extent this may be made use of in the future. The single-phase system has the advantage of great flexibility and simplicity in conversion and distribution. It is well known that three-phase locomotives, direct-current locomotives, and single-phase locomotives, can be made to operate on a single-phase system. It has been decided to electrify the whole of the Swiss State Railways on the single-phase system. As regards the question of furnaces, single-phase furnaces are bound to be used in the future, especially small ones having charges up to 2 or 3 tons. I read lately a description of a single-phase furnace having a capacity of 4,000 k.v.a. The author has already described the advantages of the single-phase furnace, so I will not say anything further on this particular subject. From the supply point of view, if the amount of single-phase power is small compared with the three-phase, that is to say, a general supply for lighting, heating, and small furnaces, this could be quite easily given from an ordinary three-phase system, especially if such system were of any magnitude. It is a well-known fact that in a polyphase system all rotating machinery, such as rotary converters, synchronous motors and induction motors, tend to balance the current and voltage on the system. Some years ago I tried to do this rather too soon when the proportion of single-phase to three-phase load was too large. We connected the Brighton Railway off-peak load to our three-phase system and were able to see the effect of the starting and stopping of the trains on the lighting in the West End, so we were obliged to give up this method until our three-phase system had increased in magnitude. In the event of the proportion of single-phase being considerable compared with the three-phase, it would then become necessary to install special apparatus such as that described by the author, or to provide a certain number of the generators with suitable damper windings. These damper windings should be of low resistance so as to compensate for the pulsating armature reaction. The use of damper windings is vital for single-phase generators, and it is also necessary that such windings should have low internal resistance. In a particular case I have in mind, when we first supplied single-phase power for traction purposes from reciprocating plant having damper windings not altogether suitable, there was a bad thunderstorm and

the lightning was causing short-circuits on the overhead equipment of the Brighton Railway. Every time a short-circuit took place the pole-shoes on the rotors flashed and one would have imagined that the whole of the rotor was burning up. This was not the case; in fact, no apparent damage was done; but it was merely the current flowing across the face of the pole-shoes owing to the damper windings being of too high resistance. There is another point with regard to damper windings. I have on more than one occasion known large turbo-alternators fail through a sustained single-phase short-circuit causing a pulsating current which damaged the windings owing to no path for the current being provided. It is of importance that the wedges for holding the field coils of every large generator should all be electrically and mechanically connected together so as to get over this difficulty. If the single-phase supply increases to any abnormal extent between any particular set of phases, I should imagine that the difficulty might be got over by connecting single-phase generators between the unbalanced phases. It would

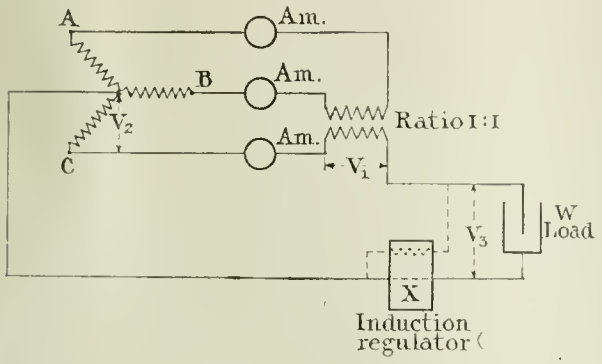



FIG. C.

be of great importance that these single-phase generators should have a lower impedance than the three-phase generators, so as to enable them to act more quickly and give the necessary out-of-balance current. Such generators, as I have said before, would have to be supplied with adequate damper windings and automatic regulators. The use of motor-generators gets over most of the difficulties. I have had experience of a motor-generator of from 1,200 to 1,500 kw. capacity which is running to-day on a three-phase system and giving a single-phase supply. The advantages of a motor-generator are that it is independent of short-circuits and low power factor on the single-phase side, and that the power factor of the main three-phase supply can be improved by its means. Some months ago I experimented with static transformers for the purpose of obtaining a single-phase supply from three-phase generators. Fig. C shows the connections. A single-phase transformer having a capacity of 250 k.v.a. and a ratio of 1 : 1 was used and connected across the phases A and B. Ammeters were placed on all three phases as shown, and voltmeters $V_1$, $V_2$, and $V_3$. The volts on open circuit were approximately as follows:— $V_1$ 6,500, $V_2$ 3,750, $V_3$ 7,500. The load was then put on by means of a water resistance W and readings were taken from zero to 50 amperes. The currents in all three phases were equal. We then shut down and short-circuited the water resistance W and made a test at approximately zero power factor. Readings of all ammeters were again taken up to 50 amperes and were found to be exactly the same. Such a system might be used for large electric furnaces, and very possibly for single-phase railways. In the event of independent regulation being necessary some form of induction regulator could be inserted at the point X so that the pressure of the single-phase system could be regulated independently of the main three-phase system.

**Mr. J. Bibby:** I will only make a few remarks on the advantages claimed for the single-arc furnace, and will take them in the order given in the paper. The first claim is that only two electrodes are required, that is, one arc. The reason for employing a number of arcs is to distribute the heating surface over the bath of metal, and not for any electrical consideration. For refining steel by the open hearth or any other process, a sufficient contact area is required between the slag and the metal to ensure that the chemical actions shall take place in a reasonable time. The necessity for a large area in turn necessitates a sufficient number of arcs to distribute the heat effectively over that area. If the heat is insufficiently distributed it is impossible to refine effectively, since the chemical actions are determined by the temperature, and any under-heated areas neutralize the effect of the fully heated areas. The larger the furnace becomes, the more necessary it is to provide a number of electrodes. The author says that the liability of the arc to cause a short-circuit is very much reduced, but surely at its worst the multi-arc furnace is in this respect only a number of single-arc furnaces. The same circumstances that would bring about short-circuits in the multi-arc furnace would do the same in a single-arc furnace, except that in the multi-arc furnace the effect of one arc short-circuit is only a fraction of that of the single arc. The same applies when the arc is ruptured; in a single-arc furnace the whole load is thrown off, whereas in a multi-arc furnace only a portion of the load is thrown off. It is stated that having only one arc enables the voltage between the terminals to be raised to almost double that which is practicable for a polyphase furnace. I think that everything which is practicable in a single-arc furnace is equally practicable in a multi-phase arc furnace, but there are good reasons for using a low voltage. It has been proved over and over again that for the refining of steel a short arc partly embedded in the slag is much better than a longer more exposed arc, which radiates more heat to the roof. Metallurgists demand a short arc, and this is the reason for its being provided; at the same time no accidents have occurred to the man working on low-voltage furnaces, whereas there have been a number of fatal accidents on the high-voltage single-arc furnaces. It is claimed that the increased voltage of the single-arc furnace leads to a corresponding reduction in current and economy in conducting cables. Suppose we have in the single-arc furnace double the voltage of a multi-arc furnace, then since in the latter we have two arcs in

series, the line voltages in each case will be the same. For example, suppose we have a Snyder furnace at 100 volts and a Héroult furnace at 50 volts, and each furnace is of 100 k.v.a. capacity. In the Snyder furnace we have to provide for 1,000 amperes going and returning, thus requiring 2 square inches total cross-section at 1,000 amperes per square inch. In the Héroult furnace we have 3 arcs of 50 volts, and therefore 667 amperes each, giving a total of 2,000 amperes and requiring, as in the case of the Snyder furnace, 2 square inches. The author says that the electrode losses depend upon the surface of carbon exposed, and that in the single-arc furnace there is a great saving in electrode consumption. In the multi-phase furnace, taken over long periods and allowing for all breakage losses and wastages, the consumption is under 10 lb. per ton of steel melted and refined, 7 lb. being for melting and 3 lb. for refining. By whatever amount the single-phase electrode consumption is below 7 lb. that is to its credit. Finally, the author states that the single-arc furnace has an exterior shape which approaches a spherical form. Now the spherical form is unsuitable for the manufacture of steel, otherwise it would have been used in the open-hearth furnace. The spherical form does not provide sufficient slag metal contact-surface, and the multi-phase furnace builders have followed the experience gained on the open-hearth furnace. I would suggest that the single-arc furnace has a spherical form from necessity, by being unable to distribute the heat over what has proved to be the correct form. This furnace is mentioned for the manufacture of steel, but I do not know of a case where a single-arc furnace is used for that purpose. It is used only for melting steel and not for manufacturing or for taking out the impurities. The single-arc furnace is always used with an acid hearth, and therefore cannot do refining. It is significant that the Snyder Company is the final recruit to the multi-phase system, and is now offering—for refining purposes—a furnace identical, electrically, with those which have been used in this country for many years.

**Mr. H. Etchells:** I feel that I must comment upon one or two points in regard to electric furnaces which are referred to in the paper and which are likely to impress engineers. Mr. Bibby has already referred to the same points, but I feel that some of them are important enough to require a little further elucidation. Primarily, by training and profession, I am a metallurgist, by virtue of necessity I am an electrician. The author says on page 109 "There can be no doubt that, putting aside all considerations of convenience of electric supply and looking at the objects to be attained merely from a metallurgical point of view, the single-phase furnace has much to recommend it." As a metallurgist I must say that I have seen nothing in the single-phase furnace to recommend it more than what I see in the multi-phase furnace of any type. To begin with, the electric furnace is used for two purposes, namely, to melt the metal, and to give it a chemical treatment after it is melted. Suppose that we have a furnace with a lining and consider the action of one electrode. In the melting of the metal, the arc eats down into the heap of metal and burrows a crater for itself, owing to the metal being more or less loosely piled. The arc does not generally continue down to the lining, because an amount of liquid metal is collected by that time into a small pool. The pool of metal gradually increases owing to the action of the arc in radiating heat to the metal surrounding it. The metal at the surface still stays there because it is more or less protected from the zone of the arc below. So long as the arc is in the shelter of that metal which surrounds it, the effect on the lining is nearly negligible. It does not matter what voltage there is on the arc during the melting process, speaking, of course, within reasonable limits; but it must be remembered that the higher the voltage the more necessary it is to put some safeguard to check short-circuit load. I am building a multi-phase furnace to-day with four electrodes with a total of 2,400 kw. capacity, and the open-circuit pressure across the arc reaches the maximum of 95 volts. The reason for using this voltage, which is higher than the normal, is that we can get greater concentration of energy during the melting period without having to increase the size of the electrodes to carry a larger current. When we come to the later stage which occurs after the metal is melted, the conditions are quite different. We have a pool of metal with slag on the surface and one or more electrodes arcing on to the surface of the slag. The arc is then not sheltered, and there is ample opportunity for radiation to the walls of the furnace. I think all electric steel metallurgists will agree with me that the higher the net voltage of the arc, the more the lining suffers, and that it is possible to have an arc of very high voltage, and of ample kilowatt capacity for the size of furnace, but which will leave the metal cold round the sides of the furnace and yet vaporize the actual constituents coming in contact with the arc at the centre of the furnace. I think Mr. Bibby hinted at somewhat the same condition of things. We have, therefore, carefully to define what we want to do with the furnace before making a statement as to which electrical system is most applicable. The particular type of furnace which has been referred to by the author is the single-phase furnace known as the "Snyder." Although a competitor of the Snyder Company, I want my remarks to be particularly free from any criticisms which might be construed as deliberately unfavourable—I want to deal with fundamentals. This particular furnace has been mainly used for melting down. It has been used, I believe, for refining afterwards, but for that purpose it has to come down to the same basis of design as all other types of furnace. The voltage has to be lowered, or else there is a danger of radiating heat on to the lining and the roof and making the refractory materials run. It will of course be realized that in stepping down from a high to a low pressure this has generally to be accomplished at the expense of less kilowatt input of energy. We come next to the question of power factor. In this particular single-phase furnace I think the voltage is about 240 on open circuit, and this drops to about 120 or 130 on load. With such a bad power factor thus necessitated, it requires fairly large leads for getting the number of kilowatts into an arc of this voltage. The higher voltage has the advantage of giving a smaller current for equivalent energy, but

bad power factor neutralizes this advantage to some extent by demanding larger current for equivalent energy. That is perhaps not of the greatest importance. What is of great importance, however, is that a furnace should be designed if only from the electric station standpoint to have as high a power factor as possible. Illustrating these remarks, I mention a furnace which I saw this morning; it is a 4-electrode furnace and has 1,300 k.v.a. behind it. It generally works at a mean load of 1,100 kw., and the recorder which is connected on the high-tension side shows regularly a maximum kick of 1,250 kw. which may last for 60 seconds, but is certainly not maintained longer. The variation from the mean load is very slight indeed. The over-all power factor of that furnace is 0·9. Now that we can bring furnaces up to such a state of efficiency in loading, I think it will be agreed that it is hardly necessary to go in for special rotary machinery in order to accomplish somewhat the same end. No steel maker installing an electric furnace desires to install a rotary machine which may need more or less constant attention. Static transformers, on the other hand, only require very occasional attention. In regard to the remarks on pages 121 and 122 as to the shape of the furnace, I do not attach much importance to the statement that the spherical design gives a maximum of efficiency owing to less heat radiation. It sounds all right in theory, but in practice the conditions are somewhat different. If we are melting a charge of steel, the steel falling to the bottom of the furnace gets no heat except what it absorbs initially; in fact, it is radiating heat to the lining all the time. Therefore, if the furnace is too deep, while the steel is getting hot on the top it is cooling on the bottom, and the depth has to be so carefully calculated that the steel in the bottom can be maintained at a temperature which will keep it reasonably fluid. Therefore, we find in general electric furnace design that it is necessary to make the bath of any electric furnace fairly shallow relatively to the diameter. I think it has already been proved that the electric arc sets up considerable alternations of the higher harmonic frequencies. Some information I was able to obtain shows that these frequencies in the arc circuit are very evident. When the load is passed through static transformers, however, the disturbing effects of these higher frequencies are damped out to a considerable extent and do not reflect to any great extent on the primary circuit. That is rather an interesting point, and I have been wondering if the converter, which the author has described, wipes out those high frequencies to as great an extent, or whether they are impressed on the high-tension side of the converter. There is also a point in regard to Fig. 6. I should like to know whether the success of this single-phase converter in giving balanced primary loads depends on having a secondary circuit approaching 45° lag, or whether the conversion is applicable to a secondary circuit with a unity power factor.

**Mr. W. M. Mordey:** The "balancer" described by the author transforms from three-phase to one-phase, transforms the voltage in any ratio required, raises the power factor on the primary side, and gives the required impedance on the secondary side. To do all these things in one machine and to do them simply is a result on which we must all congratulate the author. Although intended principally for enabling one-phase furnaces to be worked on three-phase mains, the author very properly points out that most of the one-phase furnaces in this country are used on the separate phases of a three-phase system at Bradford without any particular objection being raised. I suppose it is largely a question of scale. That part of the paper dealing with this subject of out-of-balance and its limitations is very interesting and useful, as indeed is the whole of the paper. In the iron districts where electric furnaces are mostly used there is always a large consumption of electrical energy, and this seems likely to be greatly increased by electric welding, which seems destined largely to replace riveting. The greater the general consumption the less will be the trouble about using the phases separately. The author's commendation of the one-phase steel furnace reminds me that it was our first President, Sir William Siemens, who patented and described that furnace in 1878. I have seen most of the one-phase furnaces in this country—there is something very attractive about them—perhaps the author will give the figures on which he bases the statement that their efficiency is very much higher than that of other furnaces. How much higher is it than the 800 units per ton of steel in the ladle which most makers claim? The limitation of the type seems to be the output, but up to charges of a few tons it certainly seems to be a practical success. The section of the paper dealing with the importance of stability for the purpose of preserving the lining of the furnaces (page 122, Fig. 23) is no doubt of great practical interest to electric furnace men. I imagine all steel makers are looking for a plentiful supply of zirconia, the refractory material that seems to have a great future. We know that in the Nernst lamp it stood a temperature of 2,200° C. The temperature of the steel in the furnace is about 1,700° C., but the ability to stand a high temperature is only one of the requisites of the lining. I am glad the author speaks encouragingly of the use of static condensers for power-factor correction. It is a good many years since I read a paper giving the result of certain tests and advocating the use of such condensers for that purpose.* Progress in this matter seems to have been very slow. May I mention one very small point? Why do we always speak about single-phase? We use the terms two-phase and three-phase; should we not be consistent and use the simple term one-phase?

**Mr. F. H. Clough:** Although I admire immensely the way the author has solved the problem, I am still not quite convinced that such a device is really necessary or that power factors of 70 per cent in a furnace are necessary. If he used a motor-generator having a three-phase motor and a single-phase generator, such a machine could be made to give a constant current or constant power, and practically a 100 per cent power factor throughout. Another point is that the author uses vectors to explain his diagrams, but I am rather doubtful whether in dealing with a single-phase furnace load one is fully justified in doing so, because there is

* *Journal I.E.E.*, 1909, vol. 43, p. 618.

generally considerable distortion of the wave-form and it is no longer justifiable to represent the conditions by simple revolving vectors.

**Major A. M. Taylor:** I should like to call attention to a paper recently read by Mr. F. J. Moffett before the Staffordshire Iron and Steel Institute in which the author impartially considers several types of furnaces. His remarks upon the importance of sealing up the furnace and rendering it airtight, upon the consumption of the carbon electrodes, and upon the heat lost through the electrodes and the water-cooled glands, seem to me to bear quite materially upon the question of single-phase versus three-phase furnaces. Referring now to the tests of the balancer devised by Professor Walker, as given at the foot of page 126, it would appear that the power factor of the secondary circuit, external to the machine, is as high as 0·96. From this it is deduced that there is no external reactance and that the whole of the reactance giving the curve shown in Fig. 23 is contained in the secondary winding of the machine. I wonder whether the above large reactance is inseparable from the characteristics of the machine, as in certain circumstances this might prove to be a disadvantage. I note that the power factor of the primary circuit is about 0·91 at full load; the large secondary inductance is therefore not entirely neutralized. This is a little disappointing if it represents the limit to which the power-factor improvement can be carried. It is worth noting that Mr. Moffett, in the above paper, gives 0·85 to 0·95 as the power factor with arc furnaces, whereas Professor Walker gives it as only 0·7. I should like to allude to an invention of my own, and I would point out that if an arc furnace could be got to work with 75 periods—and I understand that there are hundreds working in America at 60 periods—then my static frequency changer would be eminently suitable for use on supply systems like the Glasgow, Clyde Valley, Birmingham, South Wales, Staffordshire, Derby and Notts, London Electric, etc., which operate at 25 periods. The frequency changer has the following characteristics:—(1) no rotating parts; (2) high efficiency—estimated at 95 per cent for 500 kw.; (3) unity power factor on the secondary side, allowing enormous currents at low voltages to be supplied to the furnaces with a minimum amount of copper in the leads; (4) the property of giving a curve like that of Fig. 23 in the paper, so much commended by the author; and (5) perfect balance on all three phases whatever the load. I believe that the poor power factor on the primary side, the only weak point of the apparatus, can be rectified at a cost of about £1 per kilowatt by the Kapp or other phase-advancers where there is an opening for introducing these in a works comparatively close to the furnace. Failing this, the static condenser is being rapidly improved, and is even now a workable piece of apparatus. On a frequency changer designed for a supply of 30 kw. at 5,000 volts I have obtained 70 kw. for short periods with fair regulation, and 80 kw. with poor regulation, and moreover there is sufficient winding space to have put in the necessary copper to carry that load continuously. I have been working lately on a proposal which, if it fulfils expectations, will enable a single-phase current of any periodicity whatever to be given from the secondary at a low capital cost, with high efficiency, with a perfect balance on the primary loads, and absolutely without any moving parts. Assuming that the inherent reactance of the author's balancer can be kept low, it seems to me that a very great field is opened for such a machine, quite apart from furnace work, and I wish it every success. I do not consider, however, that the experiment quoted on page 126 proves that the balancer can deal with, say, a motor load of a poor power factor (such as 0·7) and yet give unity power factor in the primary, together with a balanced load. Perhaps the author will reply to this point and also say how the capital cost of the balancer compares with the cost of a single-phase generator at the generating station.

**Mr. H. M. Sayers:** Perhaps the most important practical point in the paper is the statement that unless a single-phase load is of the order of over 20 per cent of the whole load of a generating station the effect of unbalancing is not very important. I am interested in some applications of single-phase current where we are a little apprehensive that the supply engineers will say that we shall unbalance their systems, and I hope that they will take to heart what the author has frankly stated, viz. that while he has designed a machine which balances the system it will not usually be necessary, because moving machinery for this kind of work is both costly and troublesome. Another point, which Mr. Mordey has already mentioned, is the use of static condensers for correcting phase-unbalancing. That, I think, is extremely important, and it is to be hoped that either the author or somebody else more directly interested will push on with that question of adapting static condensers to these purposes. I believe such apparatus will solve many of the apparent difficulties in various applications of electrical power.

**Mr. H. Coates:** A machine such as that described by the author may be very useful where a supply authority like Sheffield refuses to connect single-phase furnaces to their supply, and if there is any inherent advantage with single-phase furnaces such a machine might enable them to be used in these cities. The author refers in his paper to the difficulties of regulation connected with most polyphase furnaces as distinct from single-phase furnaces, drawing our attention to the necessity of maintaining three operators on three-phase furnaces to regulate the electrodes by hand control during the first 20 minutes after the furnace has been started up from cold, in order to keep the current approximately balanced. He may not be aware, however, that a device has recently been developed to prevent this and also the dipping of electrodes, which was a common difficulty with certain three-phase furnaces. He also refers to the overall efficiency of the machine as 90·4 per cent, but it seems to me that this is a considerable loss to set against the losses which would take place in an ordinary three-phase supply system with highly efficient transformers. I think he would have to make out a very good case for a single-phase furnace in order to justify the additional expense of a special machine over the cost of the ordinary transformers and where the lower efficiency referred to would be obtained.

**Mr. W. S. Gifford**: I should like to refer to the relative advantages of single-phase and three-phase furnaces. All the early Héroult furnaces were single-phase and the original single-phase furnace designed by Dr. Héroult is still running in France. There are a number of single-phase furnaces in use, but in almost every case they have a single-phase supply. The first three furnaces we installed in England were also single-phase, working on a two-phase supply, but two of them have been replaced by three-phase ones, the reason being the great difficulty and the high expense of running the motor-generators. The furnaces were constantly being shut down on account of motor-generator trouble, and to maintain a high load factor is one of the most important points in running an electric furnace. If we have a single-phase supply for any furnace up to 5 tons' capacity we should recommend a single-phase furnace; above that we put in a three-phase furnace, for the reason that we prefer to have a large surface under the electrodes; that is, we want three electrodes for anything above 5 tons. The disadvantages of any rotary machine are the high initial cost, the low efficiency, and the difficulty of maintaining spares. With a three-phase furnace one can provide a spare static transformer without any great cost, but it would be too expensive to have a spare rotary machine in case of breakdown.

**Mr. P. F. Allan**: While I agree with Mr. Mordey that the battle between the single-phase and the multi-phase furnaces is extremely interesting to us all, and one which we should like to see fought out before the Institution, it is rather unfortunate that it should have been partly fought out over this paper, because I feel that most speakers have missed the essential point, namely, that the author has developed a new principle which may have far-reaching effects on the design of many classes of electrical machinery. The author has modestly forborne to refer to these possible effects, but I think that they may tend to remove our troubles in linking up supply systems of widely different characteristics.

**Mr. R. G. Mercer**: Since I have been at the Ministry of Munitions on electric furnace work I have seen all the different types of furnaces in every steel-works in this country and have obtained systematic returns of their operation. As regards the Snyder furnace, there are seven altogether in this country and all these are with acid bottoms and are used for making steel castings. Some of the results from these furnaces are extremely good, but the conditions under which they are running must be remembered. I have a few notes with me of furnaces up to 2 tons' capacity. With a half-ton Snyder furnace having a normal capacity of about 70 tons per month, on a typical month they got 67 tons with an average time per charge of 2·35 hours and with an average consumption of 900 units per ton in ladle (delays 28 hours). Taking a larger size of Snyder furnace, 1½ tons, I estimate the nominal capacity of a furnace of this size at about 180 tons a month. This return gives 119 actual tons at the end of the month, with an average heat period of 3·4 hours and an average current consumption of 1,035 units per ton in ladle (delays 29 hours). The author no doubt recognizes those two furnaces because both of them have his balancer. There are some other furnaces of the same make and 2-ton size which give very good results indeed, and I think those are the furnaces to which Mr. Mordey was referring just now with a nominal capacity of 240 tons a month. They give, in one case, 256 tons with an average heat period of 3·4 hours and a current consumption of 668 units, and in the other an output of 229 tons with an average heat period of 2·7 hours and an energy consumption of 666 units per ton in ladle. The 1½-ton furnace also gives very good returns; 154 tons actual against a nominal 180, 3·5 hours per charge, and 750 units per ton. These are very good results, but I think we have to compare them with others under as nearly as possible the same conditions. I will refer to another make, which happens to be the Electro-Metals. It is used on castings and is a 2-ton furnace, nominal output 240 tons, actual 227 tons, heat period 2·8 hours, and 860 units per ton in ladle (delays 13 hours). A 1½-ton Héroult furnace on castings gives 143 tons, heat period 3 hours, and 885 units per ton in ladle (delays 18 hours). A ½-ton Greaves-Etchells furnace also gives very good results. To be perfectly fair, I think that the Snyder furnace is unsuitable for any size above what Mr. Gifford mentioned, viz. 5 tons, and I should put it at somewhere about 3 tons. The biggest in this country are of 2 tons' capacity; the smallest is ¼-ton. The points about the Snyder furnace which the users and makers are agreed upon, as far as I can gather, are that the furnace operates generally very well, has a low electrode consumption, its roof stands up fairly well, and its bottom stands up well, but the bottom water-cooled electrode is unreliable—it relies entirely on water. If I were permitted to mention the number of delays—some serious—due to the bottom electrode melting away (owing to failure of the water supply), resulting in the whole of the contents of the hearth coming through the bottom of the furnace, the figures would be interesting. That is one of the main weak points of the furnace. With regard to electrode consumption, the Snyder Company are entitled to claim that they have a low electrode consumption, but there is no reason why other furnaces should not also have a low consumption. There is one running in this country with graphite electrodes and fitted with an economizer and the consumption comes down to 9 lb. of graphite per ton of metal. Where we have tried economizers on graphite and amorphous carbon electrodes, we have found a saving of 30 per cent in the electrode consumption, which is important, bearing in mind the cost of these to-day. I think it was suggested by one speaker that electrodes are rather scarce, but I know plenty of people who would gladly supply graphite electrodes from their stocks. I saw to-day for the first time an automatic voltage and current regulator, it is working on a 6-ton Greaves-Etchells furnace and so far is giving very good results. It automatically raises or lowers the electrodes throughout the whole process of melting from the cold scrap, thereby not only flattening out the load curve but effecting an appreciable saving in labour.

**Mr. J. Whitcher** (*communicated*): There is no doubt

of the great value of the author's scheme of obtaining one-phase power from a three-phase system without disturbing the phase balance beyond economical limits; but the question must still remain whether it is not more practical to avoid the necessity—in brief, whether the consuming apparatus shall not more aptly be designed to perform the balancing function in itself. The discussion must inevitably turn around this standpoint. I think that in both of the two great applications for single-phase power, traction and furnace work, this issue has yet to be decided. In respect of the former I wish to submit a proposition which is capable of practical development. I claim this because, as will be seen, the constructions and apparatus required are all such as have been abundantly proved in operation on existing undertakings. I propose simply to combine these proved methods. For instance, the Brighton Railway Company is using the extra-high-tension single-phase system between overhead trolley and rails; the other London railways are running on the low-tension system between third

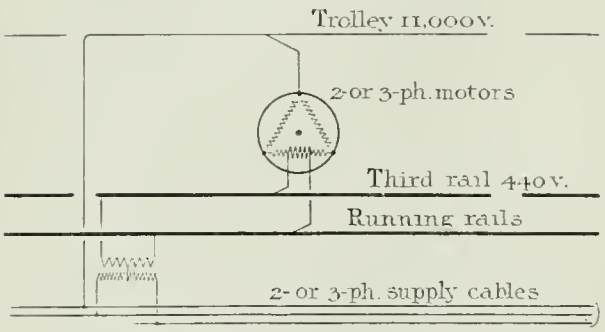



Fig. D.—Balanced two-phase or three-phase traction system.

and fourth rails. I suggest that three-phase running be secured from a single e.h.t. trolley line at, say, 11,000 volts with the other phases supplied at low tension, say 440 volts, between the third and fourth rails, or a third rail and the running rails. This can be done, and balance preserved on the e.h.t. three-phase supply system, by the method indicated in Fig. D. The overhead trolley line is one of the 11,000-volt three-phase conductors. The other two are cables, preferably cores of a three-core cable, to the one core of which the trolley is tapped at intervals. They are connected at the requisite tapping point to the primaries of static transformers, the secondaries of which are connected between the low-tension contact rails. The middle points of the primary and secondary windings of these transformers are connected together, or an auto-transformer winding may be employed. We have therefore two independent cross-phase power feeds into the train motors. These would be provided with two- or three-phase stator windings, one phase at, say, 11,000 volts, the others at 440 volts. The motors will link up the power feeds and act as the rotary balancer distributing the power demand over the three phases. It appears that this result may be obtained without transforming or phase-converting devices on the train, so that the running weight of the three-phase equipment will compare more favourably with the weights of direct-current traction equipments than single-phase equipments. Fig. D is no doubt self-explanatory; and possible developments are obvious. If we put static transformers on the train the motor voltage could be brought up to the trolley voltage on all phases, using standard windings, one-half of the power supply only requiring transformation. This might be worth doing to secure light cabling and more tractable control on heavy trains. Much more could be said of these proposals, but I simply advance the method of Fig. D for comparison with single-phase traction systems. Turning to the application to furnace work, it is clear that single-phase operation possesses a heavy practical advantage in furnaces with top and bottom electrodes. The single electrode (or group of the same) through the furnace crown will take a lot of beating in the strenuous conditions of competitive practical work. I submit, however, that a three-phase furnace can be built with one top electrode and two bottom electrodes connected up as shown in Fig. E.

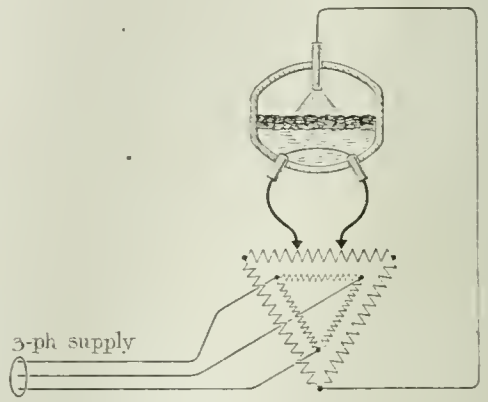



Fig. E.—Balanced three-phase furnace.

The principles involved are somewhat similar to those in the traction scheme, but the phase-balancing is to be secured by the means used for regulating the furnace arcs and currents. The voltage across the two bottom electrodes would be low, the action being as a resistance furnace in the bottom area and as an arc furnace at the usual voltages from the top electrode to the metal and each bottom electrode. One-third of the power required is to be consumed in the pure resistance path between the bottom contacts: the remaining two-thirds in the two "arc cum resistance" paths from the top contact. The arc furnace is a combined arc and resistance furnace; this method supplies a considerable proportion of the resistance component from one phase, and permits independent regulation of it. This consuming device, apart from its regulating gear, is not in itself a phase-balancing mechanism. There are, however, two circuits only to regulate. These bare ideas will not in any way distract our appreciation of the author's work, but they may add interest to the discussion.

**Professor Miles Walker** (*in reply*): The point raised by Dr. Smith as to the effect of a momentary short-circuit between two phases of a polyphase system is important. Where such a short-circuit occurs the current that flows lags with respect to the line voltage, and it brings about a momentary distortion of the voltage triangle as shown in Fig. 28. When the impedance in the furnace circuit is small, quite serious fluctuations may occur in the voltage. As shown in the paper (page 127) a furnace may be short-circuited with impunity if a balancing transformer having a high reactive drop is employed.

Mr. Partridge has asked how far the balancers described in the paper are reversible. It will be seen from the theory that all the running balancers are effective whether we are supplying single-phase power from three-phase mains or three-phase power from single-phase mains. He has very properly emphasized the importance of dampers on single-phase machines. The mechanical soundness of the connections on damper windings must always be closely attended to. The method of obtaining a single-phase load from a three-phase generator, illustrated in Fig. C, will certainly give equal currents in all three phases at all power factors, but it does not lead to a balanced three-phase load. If we assume that the transformer is a perfect one in which we can neglect the magnetizing current, the primary and secondary currents are necessarily the same in amount and phase. Further, the current in phase A is necessarily the same as the current in phase B because they are connected in series. The vector diagram of voltages and currents is given in Fig. F herewith. The voltage $V_2$ is given by the

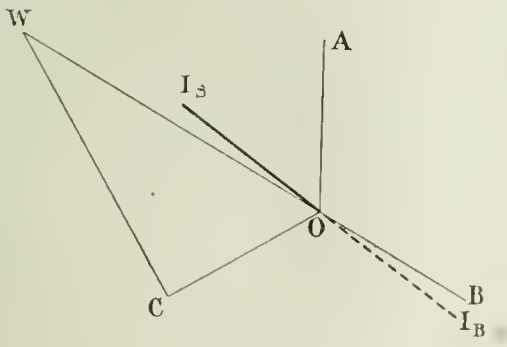



Fig. F.

vector O C, and $V_1$ by the vector C W. The resultant voltage $V_3$ is given by O W, which is in phase with O B (neglecting impedance drop in the windings). If we take a load current lagging 5° we get O $I_S$ for the current in all phases. The direction taken as positive along phase B being outwards from the star point, the dotted vector O $I_B$ gives the correct direction of the current in phase B. Thus there is a generator load of almost unity power factor on phase B, a generator load with current leading 55° in phase A, and a current lagging 65° in phase C. The disturbing effect on the generator voltage will be as bad as with an ordinary single-phase load thrown across two terminals, and there is of course the same pulsation of power as with an ordinary single-phase load.

Mr. Bibby has assumed that the single-phase furnace can only be used with one carbon at the top. It is possible, however, to use several carbons in parallel as shown in Fig. G, and then all the advantages of the wide hearth and large area of contact between slag and metal fall to the advantage of the single-phase furnace. In the polyphase furnace the difference of potential between the carbons at the top introduces the danger of a short-circuit through the semi-conducting lining, but in the single-phase type all the

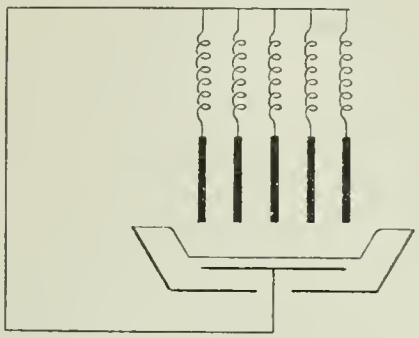


Fig. G.

top carbons are of the same potential so that there is no danger of a short-circuit between them. The reactance which is used to stabilize the furnace can be used to equalize the currents between the carbons. Where a balancing transformer of the type described in the paper is used, all that is necessary is to connect the various parallel circuits each to a separate top carbon and the reactance of the windings will equalize the currents. It is admitted that there is an advantage in having a high voltage during the melting period, as that is the period when a large electrical input is required. When we come to the refining period the voltage can be reduced in both the polyphase and single-phase types. Mr Bibby's comparison of the currents in the Snyder and Héroult furnaces is not correct. He is apparently taking his 50 volts to the star point, so that the voltage between the top carbons is 87. The Snyder furnace operated at double this voltage, or 173, would require only one carbon at the top taking 580 amperes, as compared with two carbons each carrying 667 amperes in the three-phase furnace. Of course with a little furnace of 100-kw input the advantage is not as important as in larger furnaces where the currents amount to many thousands of amperes. The spherical form of furnace is the best for melting. Single-phase furnaces with basic linings are used very largely for refining work, and where the furnace is large the number of carbons can with advantage be increased and the area of the slag surface increased to any desired amount.

Mr. Etchells admits that during the melting period there is no objection to using a high voltage. Now the melting period is the one that absorbs the main part of the energy, so that if we can cut down the current and the size of the carbons we effect a considerable

economy. In the 4-carbon polyphase furnace of 2,400 kw. capacity Mr. Etchells does not care to go higher than 95 volts between the top carbons; this gives us 14,700 amperes per phase (7,350 per carbon) and calls for very heavy connecting cables, with consequent eddy-current and contact losses. A single-phase furnace of the same capacity could be operated at 180 volts and with four carbons in parallel, each carbon carrying only 3,330 amperes. Mr. Etchells admits that the single-phase furnace is used for refining by lowering the voltage (say by means of taps on the transformer or balancer). Now the reactance of the section of the balancer winding that gives the lower voltage can be arranged so that we get full-load current (or a smaller current if need be) at any desired voltage. Mr. Etchells is quite wrong as to the power factor of the single-phase furnace. The test figures show that the power factor at the terminals of the furnace is about 0·95 (see page 126). The voltage at the terminals on load for the 400-kw. furnace was 166. As to the higher harmonics produced by the arc, these are cut down to a greater extent when a high inductance is employed as in the Snyder system, and they do not get through to the three-phase side of the balancer because the damper on the field poles keeps the flux constant. The conversion from three-phase to single-phase can be carried out on the balancer whatever the power factor of the load.

Mr. Mordey asks for the actual units per ton of steel in the ladle. The consumption of energy depends on (*a*) the size of the furnace. (*b*) the treatment of the steel, and (*c*) the care of the furnace operators not to waste energy. The last is a most important matter. The figures given by Mr. Mercer may be actual figures taken under his supervision, but there must have been a most woeful waste going on all the time, because it has been demonstrated beyond any shadow of doubt that the $1\frac{1}{2}$-ton Snyder furnace can in successive runs melt from the cold at a consumption of less than 670 units per ton. Now much less depends upon the care exercised in conserving the heat. I believe it will be possible to give Mr. Mercer an opportunity of checking these figures for himself. It is probable that the use of the term "single-phase" instead of "one-phase" arises from the fact that in a polyphase system we sometimes speak of one phase meaning one of the phases. The term single-phase has not a double meaning.

In reply to Major Taylor's questions, the high reactance is not inseparable from the characteristics. The nearer the primary and secondary windings are brought, the less the reactance. It is of course possible to get unity power factor on the three-phase side. It is more a matter of the amount of excitation of the field magnet. At the time when the test in question was taken there was a partial short-circuit of some of the field coils which was not discovered until afterwards. The power factor of the furnace measured at the terminals of the balancer is 0·95; the figure 0·7 is the internal power factor, as is evident from the description of Fig. 22.

What Mr. Clough says about the motor-generator is quite correct; the matter is referred to in the paper (page 110). The only advantages of the balancer over the motor-generator are its lower first cost and higher efficiency. Mr. Clough is wrong in supposing that clock diagrams are not applicable when the wave-form departs widely from the true wave-form. Dr. Sumpner has shown * that clock diagrams are applicable whatever the wave-form.

The method of three-phase traction put forward by Mr. Whitcher is quite possible theoretically, but it will be observed that while he obtains the advantages of both the single-phase system and the three-phase system he also has the drawbacks of the high-tension trolley combined with the cumbersomeness of the third and fourth rail. Whether such a system will be adopted will depend upon the way the balance comes out after weighing up all the advantages and disadvantages. I do not think that the method shown in Fig. E would have any advantages over the methods now employed in polyphase furnaces. The resistance of the melted metal is so low that it would require an enormous current to give a balance of phases

* *Proceedings of the Royal Society*, 1897, vol. 61, p. 455; also *Journal I.E.E.*, 1902, vol. 31, p. 630.

# PROCEEDINGS OF THE INSTITUTION.

## 616TH ORDINARY MEETING, 21 NOVEMBER, 1918.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 7th November, 1918, were taken as read, and were confirmed and signed.

The PRESIDENT: Since our last meeting a fortnight ago there has come upon us with astounding suddenness the cessation of hostilities. Then we were at war, now we are at peace, and we all, I think, find it hard to realize the altered state of things. We were strained far more than we knew and the relief is so great that few of us can find words to express our feelings or indeed yet know what our feelings are. The outstanding sensation we must all have is that of thankfulness; thankfulness to the Giver of all good that once more Peace has returned and thankfulness for the clear evidence that this world is ruled by God and not by the Devil. Truly the only Ruler of Princes has put down the Mighty from their seat and with human tools has defeated their hellish plans and maintained Right over Might. Let us beware lest we throw away our victory. Let us not listen to the fatuous suggestion that we have not been fighting the German people. The German people, whether under their Kaiser or under other men of their race, comprises the same crafty, subtle, brutal and inhuman individuals that we have had to meet during the last four years, and they are none the less dangerous because they have been defeated in the field. No area of ceded territory, no amount of payment in gold or in kind can make restitution for their bestial ill-treatment of women, for the behaviour not alone of their soldiers but of the females of their species (unworthy the name of women) towards our wounded and towards our defenceless prisoners, nor for their wanton destruction of the works of art embodying the spiritual and religious fervour of nations with whom they have nothing in common. No! only one atonement can they plead, and that can only be attained by repentance and by amendment. When they give evidence of these we can safely, and I hope shall willingly, receive them as brother men, but until that time I trust we shall be on our guard and treat them as the menace to civilization that they are, refusing to trust in any shape or way this nation of liars. Until that time let us as an Institution preserve our roll of membership free from the defilement of a known German. I ask you to rise and sing the National Anthem.

The National Anthem was heartily sung.

The PRESIDENT: In the midst of our rejoicing there are many who sorrow. During the Session we have already lost several members of Council. At our last meeting I announced the deaths of three of our members. To-day I have to announce the death of Lieutenant Llewellyn Preece, whose loss I am sure we all deeply deplore. To me personally it is a very great loss, because he was literally the oldest friend I had in the electrical industry. We were schoolboys together of the same age, and I had known him since we were 10 years old. He was taken with a most tragic suddenness; he was only ill a few days. We all mourn his loss, and I am sure that members would wish to pass a most sincere vote of condolence with his family and his immediate friends.

The resolution was carried in silence, all present standing.

The PRESIDENT: It is necessary for us to fill up vacancies as they occur by nomination by the Council. At the Council meeting this afternoon we have nominated Mr. Percy Allen to fill the vacancy created by the death of Mr. J. O. Callender.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. D. R. Broadbent and P. Hunter-Brown were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

### ELECTIONS.

*Members.*

| | |
|---|---|
| Clarke, Edward Fuhrmann. | Procter, Francis Egerton. |
| Fedden, Samuel Edgar. | Sambidge, Robert Watson. |
| Flood, Walter Herbert. | Tanner, Albert Edgar. |
| Jacoby, Henry Charles E. | Whipp, Frank. |
| Jobson, Richard Henry T. | Whipp, Samuel. |
| New, Ernest Sanford. | Wilson, Alfred Edgar. |

*Associate Members.*

| | |
|---|---|
| Adams, Douglas. | Cunningham, George James. |
| Andrews, Arthur. | Davies, Henry Onslow. |
| Armstrong, William Martin. | Davis, Percy William. |
| Babb, Herbert Charles. | Douglas, Herbert Maurice. |
| Barber, Benjamin. | Drake, John William. |
| Beasant, Henry Rainforth. | Durrant, Alfred George. |
| Bilsby, Sydney Charles. | Earnshaw, William. |
| Bird, William | Elkington, Noel. |
| Bisset, James Thomas M. | Evans, Cecil Hugh S., Lt.-Col., R.E. |
| Bitton, Benjamin John H. | |
| Boothroyd, Arthur. | Evans, Thomas Richard. |
| Bundock, Arthur William, B.Sc. | Farthing, Joseph Henry. |
| | Fitzgerald, John. |
| Burnand, Guy Cecil. | Forsdick, Charles Frederick. |
| Bury, Samuel | Frampton, Arthur Banks A. |
| Calder, James McLennan. | Goodman, Abraham Bernard. |
| Campling, Percy George. | Hanton, John Ramsay. |
| Coleman, George, Frederick. | Harris, Neill Edwin P. |
| Collins, Clifford Edward. | Hawes, Laurence Scott. |
| Cramp, Kenneth. | Hawkhead, John Clayborough. |
| Croft, Adolphus Bertie. | |

*Associate Members*—continued.

Henderson, Joseph Arthur.
Heslop, John Fearon.
Higgens, Cecil Cyprian.
Hilyer, William John.
Hodge, Warwick Guy.
Hoit, Albert.
Horne, John.
Hotchkiss, Samuel Henry T.
Howard, Cecil.
Huggett, William James.
Jackson, Thomas Frederick.
Jarratt, Alfred.
Jayne, Arthur Alfred, Major, D.S.O., M.C., R.E.
Jones, Idris.
Kimber, Arthur William.
Kitson, William.
Lake, George Harold.
Larcombe, Francis Duke.
Larcombe, Sidney Duke.
Lauper, Fred Alfred.
Law, George Cheyne.
Lazarus, Edmund George.
Leach, Robert,
Lee, Richard Henry.
Lewis, John Borlase Gwynne.
Linton, Norman Sutherland.
Lovell, William Douglas.
Lowe, Arthur Cyril.
Lydall, William Myers.
M'Dermid, Peter.
McMaster, Alexander William.
McNaul, Herbert.
Mather, James Francis.
Mayer, Edwin Thomas.
Mercer, Frank, B.Eng.
Morland, Ernest Leonard.
Murray, Arthur Richard, B.A.
Ogilvie, Francis Thomas.
Oliver, Vere Fane M., B.A.
Paiton, Robert Frank.
Percy, John Stewart.
Perryman, Lionel Walter.
Pollock, Harold.
Pritchard, Reginald Edward.
Reame, Albert.
Rhodes. William James.
Robinson, Charles.
Robinson, Frederick Harold.
Robinson, Granville.
Ross, Frederick Alexander.
Saunders, Herbert Shaw.
Shapiro, George.
Short, Sydney Thomas.
Shortridge, Gerald Herbert, B.Sc.
Smith, Charles George.
Steele, Charles Hallewell, 2nd Lt. R.E.
Stephenson, Ernest Fortunatus.
Stewart, Archibald Conacher, B.Sc.
Stickland, Harold Meering.
Stigant, Stanley Austen.
Street, Percy Hodges.
Thomas, John.
Thomas, Thomas Stanley.
Thomson, William Graham.
Tracey, Albert Isaac.
Vice, John Armston.
Walsh, Edward Joseph.
Webb, Frederick Henry.
Webb, Samuel Henry.
Westgate, Hugh Arthur L.
Williams, Llewelyn Elias.
Young, Harry Clarance.
Young, James, Capt. R.A.F.

*Associate.*

Woodcock, William Edwin.

*Graduates.*

Andrew, Duncan Carmichael.
Aylott, Henry Joseph.
Baker, Charles Ernest.
Brierley, Ernest.
Cluley, Gordon.
Cooper, Claude Maxwell.
Cressey, John Alfred, Sapper, L.E.E.
Devoy, James William A.

*Graduates*—continued.

Eliades, Jacques Elie.
Hunter, George.
Jacobs, Edward.
Jaques, Henry Hugh.
Jefford, Joseph Wilfrid.
Lauwers, Rene.
Macqueen, George Daniel B.
Page, Arthur.
Palmer, Thomas Henry.
Russell, Cecil Ruffel, Lieut. R.E.
Shute, Reginald Joseph G.
Slater, William John.
Squire, Reginald George H.
Tessi, Arturo Alberto.
Webb, Arthur William.

*Students.*

Beacon, Francis Herbert.
Booth, John Arthur.
Craig, Samuel.
Cronin, Bernard Augustine.
Duncan, Jack Stewart.
England, Benjamin.
Harding, Albert Victor.
Howe, Alfred Henry.
James, William Samuel.
Marshall, Joseph Francis.
Martins, Fausto Bebianno.
Metz, Louis Gerald E.
Mitchell, Osborne Sinden.
Peacock, Charles Duncombe.
Sclar, Isaac.
Waizborn, Harold.
Welsford, Douglas.

TRANSFERS.

*Associate Member to Member.*

McWhirter, Alexander Simpson, B.Sc.

*Associate to Associate Member.*

Mortimer, Harold Edward.

*Graduate to Associate Member.*

Harris, Henry Kingsford, M.A.
Pottle, Ernest Herbert.
Silcock, Richard.
Waygood, Oscar Candish.

*Student to Associate Member.*

Whitaker, George Backhouse.

*Student to Graduate.*

Baker, Frederick Norman.
Critcher, William Thomas.
Dos Santos, Antonio Victor.
Duckworth, Ferdinand Farrant.
Lye, Donovan Henry C., Lt. R.A.F.
Nichols, Gerald Richard.
Pendlebury, Stanley.
Voss, Hermann Albertus.
Wells, Vernon Henry.

A paper by Mr. J. H. Shaw, Associate Member, entitled "The Use of High-pressure and High-temperature Steam in Large Power Stations" (see page 73) was read and discussed, and the meeting adjourned at 7.45 p.m.

## 617TH ORDINARY MEETING, 5 DECEMBER, 1918.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 21st November, 1918, were taken as read, and were confirmed and signed.

The PRESIDENT announced that the Council had unanimously elected Professor A. E. Kennelly, D.Sc., of Harvard University to be an Honorary Member of the Institution; also that Mr. W. Judd of the Eastern Telegraph Company had been elected to fill the vacancy on the Council caused by the death of the late Lieutenant W. Ll. Preece.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. F. Williams and J. H. Johnson were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

*Associate Members.*

Barnett, Frederic John.
Chamier, William, Capt. R.M.E.
Denness, Thomas, Capt. R.E.
Dixon, Isaac Tunnah.
Foster, Ellice Guise.
James, Edmund Whitcombe.
Lesniewski, Witold.
Newey, Frederick.
Quick, Henry James.
Redmayne, William.
Wilkes, Sydney.

*Graduates.*

Petry, Martin.
Tinker, Cecil Franklyn.

TRANSFERS.

*Associate Member to Member.*

Hazel, Harry Curwen.
Holliday, Harry.
Nash, George Howard, C.B.E.
Pemberton, Samuel Thomas.
Phillips, Ernest George.
Shaw, John Henry.
Swainson, Laurance Webster.
Thompson, Paul Sommerville.

*Graduate to Member.*

Bexon, William Collier.

*Graduate to Associate Member.*

Collyer, John Edward E.
Geary, Frederick Arthur.
Lewis, Edward.
Manley, George Thomas.
Meade, John Henry.
Millns, Percy Maurice.
Owen, Robert Elias L.
Owen, William Emlyn.
Platt, Frank Cuthbert.
Simpson, Francis Augustus.
Smith, Maxwell.
Sylvester, Cyril.
Treherne, John Wilfred.
Vine, Bertrand James.
Wells, Reginald Iredale.

*Student to Associate Member.*

Alvey, George Burton.
Arrowsmith, Sydney John.
Beavis, Edgar Alan.
Berry, Thomas Butland, Capt. R.E.
Chadwick, Albert Thomas.
Churcher, Brian Andrew G.
Clifford-Smith, Douglas Horace.
Hews, Cyril James.
Mackie, Arthur Perrott.
Prothero, Edward Loyd M.
Saxton, Clement.
Spencer, William Gordon, M.Sc. (Tech.).

*Student to Graduate.*

Carter, Frank.
Mantle, Rowland Shelley.
Narasingarao, Chapa Venkata L.

The PRESIDENT : The Committee set up to consider the question of a War Memorial have fully discussed the matter and an appeal will very shortly be issued. I desire to commend it most heartily to members and I trust that we shall have the assistance of the Press in making widely known the object, which I hope and believe will commend itself to every member of the electrical industry.

A paper by Professor Miles Walker, D.Sc., Member, entitled " The Supply of Single-phase Power from Three-phase Systems " (see page 109), was read and discussed, and the meeting adjourned at 8 p.m.

618TH ORDINARY MEETING, 12 DECEMBER, 1918.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 5th December, 1918, were taken as read, and were confirmed and signed.

The PRESIDENT : There are one or two announcements which I wish to make in connection with the Council meeting held this afternoon. First, Mr. R. W. Paul has very generously presented £500 to the Institution to be used for fostering the development of methods and means for electrical measurements. The details of the scheme for giving effect to his donation will be announced later. Secondly, Mr. A. H. Preece has sent this time-stained document which is dated from Westminster Chambers, Victoria-street, London, 26th January, 1871. It is from Major Frank Bolton, one of the founders of the Institution, to R. S. Culley, Esq., and relates to the founding of the Society of Telegraph Engineers. (The letter is reproduced in *Institution Notes*, No. 10, page 10, January 1919.) We are very much indebted to Mr. Preece for this most interesting document. Thirdly, as the result of representations made to the Council in regard to the destroyed libraries in Serbia (see *Institution Notes*, No. 10, page 11, we have decided to-day to present a set of bound volumes of the Institution *Journal* for the last 20 years, to make a grant of £50 for the purchase of British technical works, and to appeal to members for copies of British books on engineering. Mr. Ll. B. Atkinson has generously offered a complete set of the *Proceedings* of the Institution of Civil Engineers dating back to the eighties. We are also suggesting that catalogues of British manufactures should be sent by the various firms, such catalogues being in French, for the information of the Serbians as to the products of our manufacturing firms. Finally, it has been decided that arrangements shall be made for the celebration of Peace later in the year, probably in the summer, by some entertainment and reception definitely welcoming back as many as possible of our members who have been serving in His Majesty's Forces. It is also proposed to hold the Annual Dinner again this

year in April or May, when it may be presumed most of such members will have returned.

A discussion on "Electric Welding" then took place, an introductory paper being read by Mr. H. M. Sayers, Member, entitled "Notes on Regulations for Arc Welding." The object of the discussion was to ascertain, for the information of an Admiralty Committee who were considering regulations for electric welding, the views of the industry in regard to the requirements for the protection of operators and others.

The meeting adjourned at 8.15 p.m.

## 619TH ORDINARY MEETING, 19 DECEMBER, 1918.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 12th December, 1918, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. D. R. Broadbent and H. R. Green were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

### ELECTIONS.

*Associate Members.*

Apthorpe, William Herbert.
Duncan, William.
Elliott, Helmer.
Hastings, Alfred John.
Hill, Henry, B.Sc. (Eng.).
Hobbs, Horace Henry.
McGill, Ernest William.
Morecombe, William Maurice N., B.Sc. (Eng.).
Morrison, Robert Leonard.
Parry, William, M.Eng.
Ritchie, William Gardner.
Rockey, Basil Samuel S.
Sanders, Henry Edward.
Sarvent, James Frederick.
Scott, Henry Charles F.
Selley, Frank.
Simpson, William Wilson.
Walsh, John William T., M.A., M.Sc.
Watson, Donald Davis.
Young, Henry Thomas.

*Graduates.*

Barnes, Lionel Frederick.
Buckland, Bert.
Collins, Thomas Lewis.
Cull, Edward Charles, B.Sc.
Cummings, John Hallett.
De Moss, George Henry.

*Graduates*—continued.

Pearce, William Edward, B.Sc.
Watson, Robert Cecil, B.Eng.
Whiteside, Richard.

STUDENTS.

Burke, John.
Dickinson, Richard Heath.
Forster, Samuel Alexander S.
May, Albert Edward.

TRANSFERS.

*Associate Member to Member.*

Carr, Laurence Hudson A., M.Sc. (Tech.).
Coates, Henry.

*Graduate to Associate Member.*

Curling, Harold William, Capt. M.C., R.A.S.C.
Highfield, Frank William.
Hollands, Edwin Frank.
Jockel, Lauret Marshall.
Lamb, Hugh Reginald.
Radforth, Walter Ernest.

*Student to Associate Member.*

Kilburne, Roy Goodwin.

A paper by Mr. P. Hunter-Brown, Associate Member, entitled "Carbon Brushes: Considered in Relation to the Design and Operation of Electrical Machinery," was read and discussed, and the meeting adjourned at 8 p.m.

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# PLANNING A WORKS RESEARCH ORGANIZATION.

By A. P. M. Fleming, O.B.E., Member.

(*Paper first received* 13 *October, and in final form* 28 *November*, 1918; *read before* The Institution 23 *January, before the* North-Eastern Centre 20 *January, before the* South Midland Centre 5 *February, and before the* North-Western Centre 11 *February*, 1919.)

Synopsis.

Introduction.
I. Functions of the organization.
II. Divisions of the organization.
III. Administration.
IV. Staff.
V. Design and equipment of buildings.
Determination of floor area.
Types of buildings.
Selection of fabric.
Elimination of vibration.
Lighting.
Fire protection.
Arrangement of sections.
Water, gas, and electric supplies.
Heating and ventilation.
Internal finish.
Furniture.
Costs.
Conclusions.

## Introduction.

No plans for the future development of industry are now considered complete unless they provide for scientific research, and although this is necessary to a greater or lesser degree in all industries, in no industry is there such scope for research as in the highly technical electrical industry.

During the past few years there has been a great deal of research directly controlled by or associated with industry. For instance, while universities and technical colleges have in the past conducted research, only a fraction of which has been directed to industrial requirements, the tendency is for an increasing proportion of the research carried out in such institutions to be of an industrial character. Various other laboratories and organizations, together with scientific and engineering societies, have either conducted or financially supported research in connection with their interests.

In a national sense, the Department of Scientific and Industrial Research with its large Treasury grant is endeavouring by the establishment of research associations to develop means whereby co-operative research can be established in various industries, with the initial assistance of Government funds.

Many of these laboratories will provide new industrial knowledge for the common use of those able to make use of it, and, while there is need for them, the individual manufacturer invariably has his own immediate problems for which he requires special provision directly under his control. In such cases he has to consider whether he should establish his own research organization, or whether he can be efficiently and suitably served by research associations, university, or other laboratories. Whatever facilities are available it is clear that in many instances it is advisable for firms—particularly large ones—to establish research organizations in connection with their own factories

The purpose of this paper is primarily to outline the scope of such a research organization, the features which underlie its effective planning, its requirements with respect to staff; the design of the buildings and the initial outlay and cost of maintenance of the organization. It will be appreciated that different industries and different firms even in the same industry, have varying needs; consequently in the scope of a short paper only broad treatment of the subject is possible It is hoped, however, from the data thus provided, taken from modern laboratories in different parts of the industrial world, that sufficient guidance will be afforded to enable those who so desire to plan the essential features of a research organization for themselves

## I. Functions of the Organization.

The function of an industrial research organization in its broadest sense is to acquire and to apply all the knowledge and experience which can assist the advancement of the industry, since it is only by the application of new knowledge and experience that progress is made.

It is necessary to draw a clear distinction between research work in pure science and industrial research. Both are essential to industrial progress, the former being directed towards widening the boundaries of knowledge, formulating principles and revealing relationships that are the raw material of the latter, which is generally directed towards the solution of some specific industrial problem or towards meeting some industrial need.

The justification for undertaking research in pure science in a research laboratory associated with an industrial concern lies in the almost inevitable industrial applications which follow rapidly in the wake of a new scientific discovery, and it should be noted that the functions of the scientist, industrial worker, and manufacturer are equally necessary in rendering the ultimate product of a new discovery available to the public. It is questionable from the economic point of view, however, whether the majority of works laboratories should undertake such research, since only a fraction of the new knowledge produced is likely to be of value to one particular works. Much of this work, therefore, must be carried on as hitherto by scientists working in private, university, co-operative or national laboratories. On the other hand, in very large laboratories in complex industries, particularly where special products resulting from discoveries can be manufactured, the undertaking of research in pure science may be of very great value.

Research laboratories partly or wholly supported by industrial firms may be broadly classified according to the particular interests they are intended to serve, as for example :—

(1) Industrial research laboratories self-contained and serving one particular works.

(2) Central industrial laboratories each forming the scientific focus of an industrial organization comprising several works, often in different industries, and linked up by control laboratories at the individual works. The function of the central laboratory is to conduct research bearing on the manufactures of all the works, and that of each control laboratory is to serve the immediate requirements of the works to which it is attached.

(3) Laboratories planned to serve a wide range of interests in various industries in connection with isolated problems, such as the Mellon Institute of Industrial Research, Pittsburgh, or ordinary commercial laboratories such as that of A. D. Little & Co., Boston.

(4) Laboratories designed to serve the needs of one particular industry working on a co-operative basis such as the Laboratory of the National Canners' Association, U.S.A. The laboratories of the proposed research associations in Great Britain would fall into this class.

(5) State laboratories carrying out researches occasionally of an industrial character, but not necessarily for any particular firm, such as the National Physical Laboratory, the Bureau of Standards, U.S.A., and various university laboratories.

The majority of firms, particularly when commencing research work, find it expedient to combine necessary routine testing with research work, at any rate in the initial stages of development. There are many reasons in favour of this course. Both routine testing and research have much in common and can make use of the same building and much of the same equipment. The routine testing department serves as a training ground and nursery for some members of the research staff. Further, through the work involved in routine testing the research department is kept in close contact with other works departments.

In the later stages of development, however, and especially in large and complex organizations comprising several works each requiring routine testing, it becomes desirable to establish a separate and, if possible, central laboratory for research work alone, together with local control laboratories.

The laboratories referred to and illustrated in this paper are considered to comprise both routine and research work, as their combination is the policy most likely to be adopted by manufacturers initiating research organizations.

The functions of such a works research organization, which involve arrangement of the department in a number of sections, may be classified thus :—

(1) Testing of raw material supplies and the establishment of a suitable technical basis for purchasing.

(2) Production of new materials or substitutes for those already in use, as for instance, high-speed tool-steels, improved magnetic sheet steel, etc.

(3) Investigation of difficulties arising in the manufacturing organization.

(4) Investigations necessary for controlling and maintaining at their proper level technical processes in manufacture.

(5) Development of new and improved processes and their establishment on a manufacturing scale on most economical lines.

(6) Development of methods for the treatment of factory waste and scrap for by-products.

(7) Investigation of phenomena required in the compilation of fundamental data for designing new apparatus.

(8) Development of new tools, appliances and methods of testing; improvement and standardization of those existing.

(9) Investigations of operating troubles and service for customers.

(10) Investigations for the information of financiers of the possibilities of new projects of a scientific character.

(11) Physiological and psychological investigations relating to vocational selection and for determining the most efficient means of employing human services.

(12) Research in pure science.

## II. Divisions of the Organization.

The character of the industry determines mainly the scope and nature of the work to be done and, consequently, the number of sections of the laboratory. In rolling mills, for example, sections devoted to chemical, metallurgical, microscopic, and physical testing are sufficient to meet the main requirements. In the electrical and allied industries the number of sections is perhaps as great as will be found in any industry. These are given below, together with a brief statement of their functions for the general kinds of electrical and mechanical engineering works. In the case of a small works, some sections, such as the workshop, may

be provided in the manufacturing departments. It will be noted that some of these sections deal wholly or largely with routine testing and that these are subsidiary to other sections.

*Chemical* (*Organic and Inorganic*).—Co-operating with all other sections and undertaking routine analysis of incoming materials, ferrous, non-ferrous and organic for works use, and of materials in process of manufacture, and investigating and standardizing speedy methods of routine testing.

*Mechanical testing.*—Dealing with all routine tensile, transverse, compression, hardness, and torsion tests on metals and alloys in sheet, rod, or wire form; tests on textile fabrics, papers, fibre and other insulating materials, cements, etc.; destruction tests on assembled parts and the testing of scale models.

*Metallurgical* (*Ferrous and Non-Ferrous*).—Responsible for advising on the suitability of metals and their appropriate treatment for use in apparatus and in works equipment and tools; for supervising annealing and other heat treatment processes; for the conduct of investigations for the production of improved metals and alloys; for investigating failures in metals.

*Photo-micrographic.*—Co-operating with the metallurgical and other sections in preparing specimens for microscopic examination and in photographing the same.

*Electrical.*—Responsible for special tests on insulators, conductors and resistances, both when received and as required during manufacture; for special tests on finished machines, oscillograph investigations, etc.

*Magnetic.*—Responsible for tests on steel forgings and electrical sheet steel for permeability, hysteresis, and eddy losses, and on permanent magnets for remanence and coercivity.

*Optical.*—Dealing with investigations and tests of an optical character, such as the examination of large forgings by optical and X-ray methods; the application of colour testing to routine work, optical examination of screw threads and gauges.

*Illuminating.*—Undertaking investigations in connection with lamp manufacture.

*Physical.*—Undertaking all investigations of a physical character not optical or electrical, such as investigations connected with standards of measurement, heat transmission, acoustics, etc.

*Pyrometric.*—Responsible for the standardization, repair, regular checking and supervision of works pyrometers; selection and installation of appropriate instruments where required and manufacture of spare parts for works use; advising on thermostatic control, methods of high-temperature measurement, refractory materials.

*Materials.*—Responsible for the standard quality of materials used in the works, and for the acceptance of materials purchased after appropriate chemical, mechanical, electrical, microscopic and inspection tests. This section draws up specifications to define the limits of variation of sizes and properties of standard materials where required, and secures uniformity of practice throughout the works. It undertakes investigations into defective materials for which special provision is not otherwise made.

*Technical processes.*—Dealing with the development of new or the improvement of existing processes, particularly those giving trouble in the shops, and requiring the services of expert engineers in a suitable laboratory. Technical supervision may also be exercised over works processes, such as electro-plating, galvanizing, sherardizing, electric arc, resistance, and spot welding, insulating processes of various kinds, casting, painting and varnishing, and their modes of procedure crystallized in specifications. The development of new processes requires the employment of plant of a semi-manufacturing scale after preliminary small scale laboratory experiment before the process can be placed in the shops. A most important function of this section is to remove as far as is practicable all experimental work from departments the true purpose of which is manufacturing.

*By-products.*—Responsible for recovering usable products from factory waste and scrap such as oils, metals, and insulating materials. In addition, this section may conveniently be equipped for the preparation of oils, solders, cements, fluxes, special insulating compounds, paints and varnishes where these are special to the works or where they can be prepared more cheaply than they can be purchased outside.

*Psychological and physiological.*—Modern methods of engaging employees, particularly juveniles, and of determining a basis for promotion involve the development of psychological tests of intelligence. The evolution of tests of proved validity involves continuous investigation in a laboratory of applied psychology.

*Workshop.*—For the manufacture of small parts, instruments, etc., and for the preparation of specimens for physical testing, a small workshop is required, fitted with the commoner types of machines, lathes, drilling, milling and shaping machines and hand tools.

*Intelligence and information section.*—It is important in a research organization to prevent the expenditure of time and money on investigations which have been carried out previously, either inside or outside the organization, the results of which can be made available for reference. Information of this character may be collected much more economically and thoroughly by a small trained staff than through the promiscuous efforts of the research workers themselves. The information thus collected would form the Research Library, also under the control of this section. Such a section would serve as a focus and a co-ordinating centre for the research department, and would also facilitate relations between the works and the department and between the department and outside institutions. The section further becomes a repository for the reports of work done in the research department. Too much stress cannot be laid on the importance of keeping adequate records, setting forth not only the causes bringing about the need for research, but full details of the investigations, the methods employed, apparatus used, the deductions drawn from results, and a special note of any further researches arising out of the particular investigation reported. It may not be possible to carry out subsidiary investigations at the time but they may be of sufficient importance to be considered subsequently. In preparing a report, a standard plan is desirable.

*Administrative.*—Accommodation must be provided in the laboratory building for the staff dealing with the administration of the research organization. It will be the duty of part of this staff to maintain a proper record of costs of investigations. In some laboratories it is usual for a sum to be set aside for each major investigation; in others, an overall sum is voted each year for the maintenance of the laboratory. Where routine work is done the cost of this may be charged against the works department on behalf of which the expense is incurred. In any case, a systematic record of all costs, stores, breakages and wages, subdivided according to the various investigations, is of great importance.

## III. Administration.

The internal organization of an industrial research laboratory depends largely upon the nature of the work undertaken. Where it comprises routine testing for works departments the nature and number of the tests carried out form a series of sections each having a departmental chief responsible to the director, and a staff of senior and junior assistants to carry on the work and to provide for continuity in case of transfer or promotion. Where research work of a kind not immediately related to works practice is concerned each major investigation should be placed in the hands of a competent specialist, working with or without assistance, but directly responsible to the director. Where work is combined, as will generally be the case, both methods may be employed.

In either case, the work of the staff is greatly facilitated by regular conferences of the departmental chiefs and research workers, as in this way the progress of work of interest to more than one section can be discussed and the cumulative experience of the whole staff be brought to bear on new problems. Overlapping and duplication of work can also be avoided, a possibility which may frequently arise when every part of a problem has to be analysed and different aspects minutely studied by different workers.

It may be noted that the method of organization for routine tests referred to involves a minimum of floor space, equipment, and apparatus for a given volume of work. Also it facilitates the training of young men not only for higher positions in the research department, but also for other parts of the organization, such as the supervision of technical processes.

With regard to working hours and discipline, the staff of an industrial research laboratory should conform to the practice of the works with which it is associated. Where, as in the examples of laboratories thus far considered, the work of the laboratory is partly of a routine character, it is important that the closest co-operation should exist between the staff engaged more specifically in research and those engaged in routine work, and especially also between the whole of the laboratory staff and the works staff. Many investigations arising in works practice involve little more than the interpretation of evidence revealed by routine tests. The heads of sections carrying out routine tests should endeavour to keep informed of the most up-to-date methods of procedure, thereby enabling the staff to be kept to a minimum number of high-grade workers.

## IV. Staff

The most important feature of a research organization is that of the staff. This country has for centuries produced a succession of distinguished scientists, especially physicists, and at the present time there is no lack of gifted men who are able to extend the boundaries of knowledge. It has, on the other hand, been repeatedly emphasized that there has been a lack of technically-trained young men who are able to apply the results of scientific research in industry. The demand was not sufficient to stimulate a suitable supply. The experience of the war period has changed the attitude of industry considerably in this respect, and the inducement offered to university men to enter research work is much greater than hitherto. As far as the limited supply of students permits, the universities have endeavoured to respond, and the scholarships now being awarded, together with the assistance offered by the Department of Scientific and Industrial Research, should do much to encourage students still further. For a considerable time to come, however, the supply of men will be totally insufficient for the needs of industry.

It is an error to suppose that industrial research cannot be carried on without men of genius of the type which has been responsible for many brilliant advances in the past, frequently under considerable personal difficulties and without adequate experimental equipment. Such a type, indeed, is generally not at ease in an industrial works where research can be reduced to the character of a business, where procedure can be organized on systematic lines towards a clearly defined objective, and where progress can be made by co-operative effort of resourceful, energetic, well-trained, but otherwise ordinary men.

With the exception of those actually engaged in directing research, the staff should comprise comparatively young men and women capable of distinguishing cause from effect, able to observe keenly and possessing sound technical training, preferably of university standard in the faculty pertaining to the industry they propose to enter, followed by some practical experience. Graduates who have shown during their university career that reasoning capacity, knowledge, resource, and skill in manipulation which comprise aptitude for research, might proceed to a works for a period of practical training and then return to the university for a post-graduate course in research before entering the works organization. Alternatively, students may enter the works for practical experience on concluding a post-graduate course, subsequently being placed in the research department.

In addition to serving as a nursery for research workers, the laboratories should undertake part of the training of all those young men who in a large organization are being trained for higher industrial positions, as, for instance, many of those on the designing, commercial, or works management sides. In this way the industry becomes permeated with men having a keen appreciation of the value of scientific method. In connection with the section dealing with works processes, some of these

men, promoted possibly from the trade apprentice course, may ultimately be permanently employed. Others would be transferred to the works, where they could utilize their experience in the direction of such processes.

In view of the limited supply of research workers, it is essential that the research department should work in close contact with the educational portion of the organization now becoming an essential feature in industrial concerns, since the latter would control the selection, training, and promotion of all grades of apprentices. Every possible step should be taken to reveal latent talent, and to provide opportunities for acquisition of the necessary education and experience.

The universities can only partially complete the training of the staff required for industrial research. This may be illustrated by the procedure adopted at the Mellon Institute of Industrial Research, Pittsburgh, which was founded for the express purpose of conducting researches for manufacturers, the work being undertaken by Research Fellows selected principally from the universities. These men co-operate closely with the works concerned and frequently become absorbed into its staff at the conclusion of the research.

The staff of an industrial research organization, comprising sections as indicated above, will generally include a director, sectional heads, senior and junior assistants, with possibly a number of individual research men responsible to the director. The function of the director calls for special consideration. He must appreciate the possibilities of applying new knowledge to industry to commercial advantage, and be able efficiently to direct specialized research workers, avoiding aimless research having no utilitarian objective. While he requires a wide scientific knowledge to be able to follow intelligently and appreciate the trend of scientific development, he must have in addition considerable organizing capacity, commercial instinct, and a thorough knowledge of the manufacturing processes of this industry. He must have sufficient breadth of view to be willing to employ expert assistance whenever occasion for this arises.

The sectional heads will, in general, be men of high scientific standing, especially in their particular branch of science. These, and the senior staff, should be men of university education and training. It is essential that every position in the department should be filled by the best available man for the post, and the research staff should be considered to offer the most highly prized positions, unsuitable men being transferred to other parts of the works organization.

### V. Design and Equipment of Buildings.

In designing laboratory buildings the advice of a competent architect is necessary in all matters of a purely architectural character. These, however, should be subservient to the considerations which decide some forms of construction and some arrangements most appropriate to the laboratory as such. While individual concerns have widely varied work to perform even in the same industry, buildings devoted to laboratory work all have some features in common. The research laboratories should be contained in a building separate from but centrally situated in relation to the works departments.

The size of the laboratory will be determined mainly by such considerations as the number and character

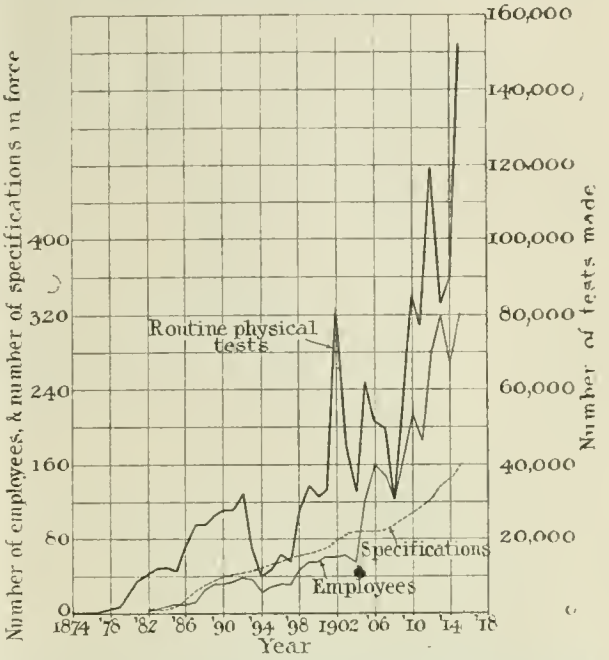



Fig. 1.—Growth of work and staff of the Research Laboratories of the Pennsylvania Railroad Co.

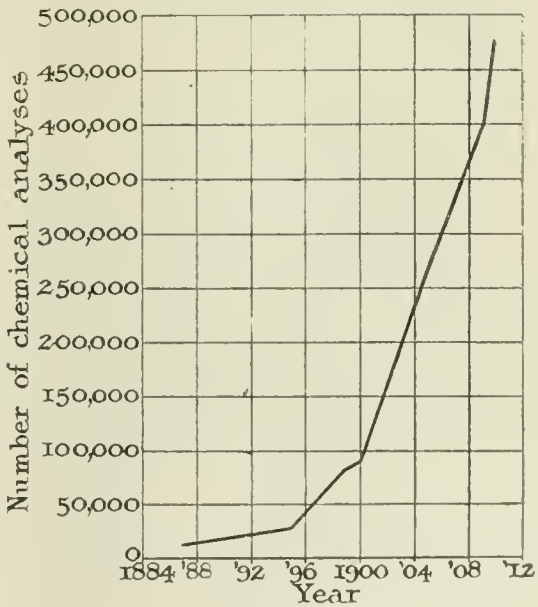



Fig. 2.—Growth of work in Chemical Laboratories of F. Krupp A.G., Essen.

of the sections, the volume of work, size of staff, margin allowed for extension and the amount of money available for initial outlay and maintenance.

The importance of providing a liberal amount of

FRONT-ELEVATION

FIG. 3.

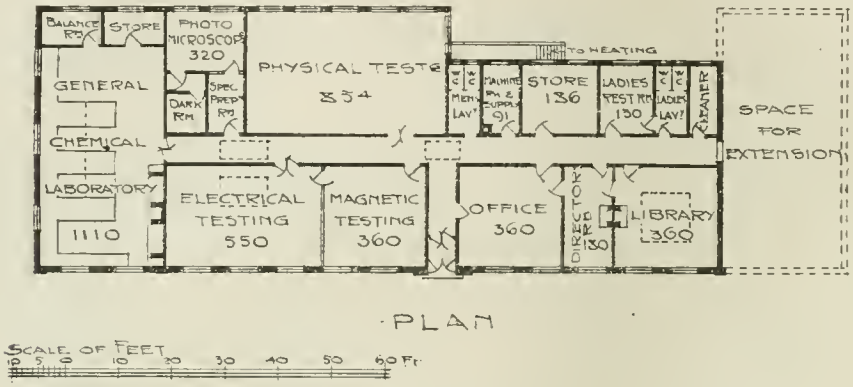



FIG. 4.

FIGS. 3 AND 4.—Single-story research building, 5,500 sq. ft. gross floor area.

FRONT-ELEVATION

FIG. 5.

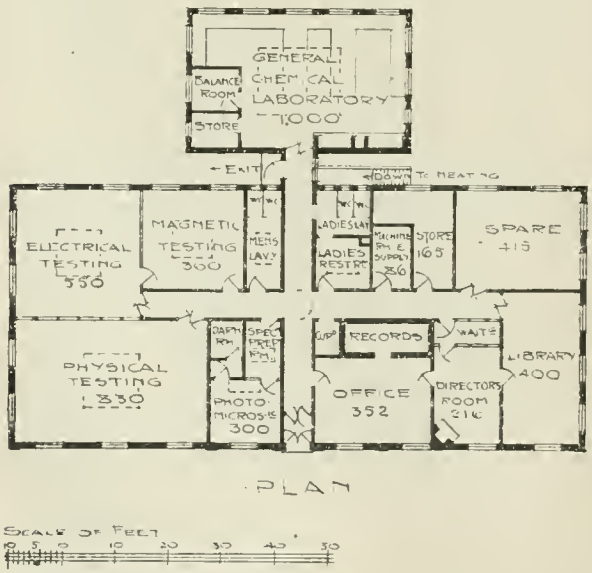



FIG. 6.

FIGS. 5 AND 6.—Single-story research building, 6,000 sq. ft. gross floor area.

space initially and of adopting a design of building which permits extension without undue cost or inconvenience is emphasized by Figs. 1 and 2, which show the rate of increase in certain activities in the laboratories of the Pennsylvania Railroad Company, U.S.A., and F. Krupp A.G., Essen.

*Determination of floor area.*—In determining the amount of floor space required, it is first of all necessary to compute from the amount and character of the work to be undertaken the number of sections and the staff needed for each.

The average active floor area—that is floor area actually required for working, excluding space required for stores, etc.—required per employee in all usual sections of an industrial research laboratory is from 150 to 250 sq. ft. In some sections, of course, where the equipment is of a large size, as in mechanical testing, a larger area is needed.

Where the lower figure is employed any appreciable increase in the work of the organization will necessitate extension of premises. On the other hand, the higher figure represents fairly comfortable conditions, and provides some room for extension. It should not, however, be regarded as a maximum. The guiding principle should be to make the provision of premises and equipment as liberal as circumstances permit, and when financial considerations do not preclude it, an average of 400 sq. ft. of active floor area per employee—a figure commonly found in the large research institutions in the United States—must not be regarded as excessive.

From the product of the total staff and the floor space allowed per employee, the total active floor space is obtained. To this must be added 10–20 per cent for space occupied by stores, lavatories, heating, ventila-

tion, and power plant. The space lost in containing walls, corridors, partitions, and stairways, will necessitate a further addition of 15 per cent to 40 per cent to the active floor area, being under ordinary conditions on the amount required per employee. In some laboratories it may be found that a greater administrative staff or a greater proportion of junior or non-technical trained staff is required than in others. In

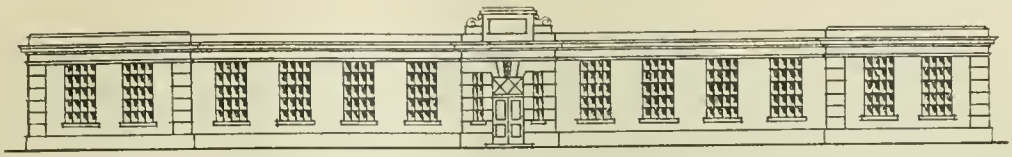



FIG. 7.

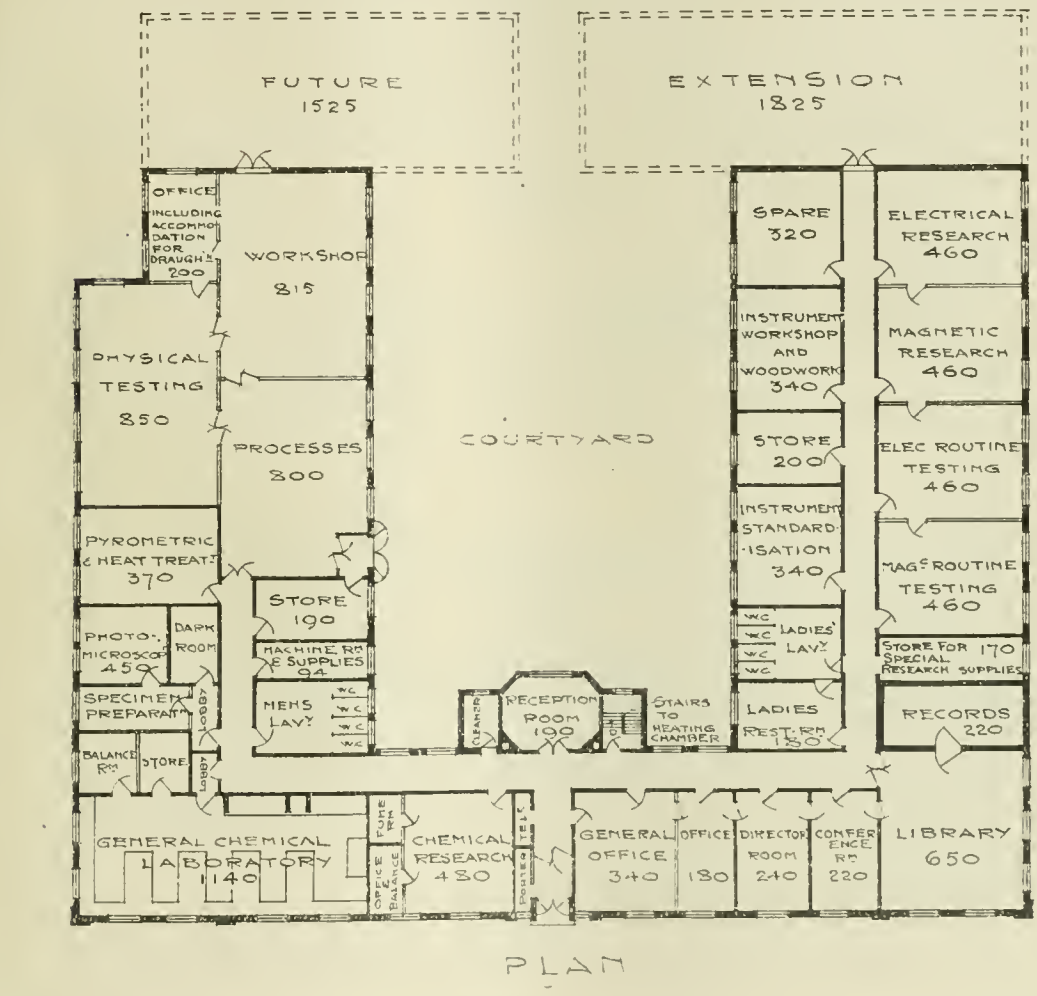



FIG. 8.

FIGS. 7 AND 8.—Single-story research building, 13,400 sq. ft. gross floor area.

about 20 per cent in a single story and 33 per cent in a multi-story building. The active floor area must therefore be increased by 30 to 50 per cent to arrive at the gross floor area.

It should be noted that the floor area is estimated general, however, the proportion between the total number of employees and the percentage actually engaged in investigational work will not vary very greatly in different laboratories.

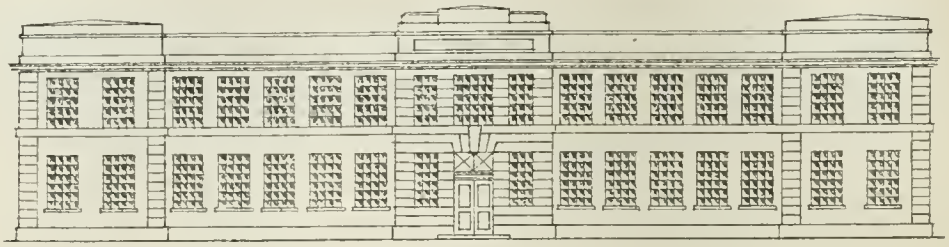
*Type of building.* — The type of building may be

determined by the gross floor area needed and generally will be one of the following :—

(1) For a gross floor area up to about 6,000 sq. ft. a single-story building of rectangular form in plan, as illustrated in Figs. 3, 4, 5, and 6.

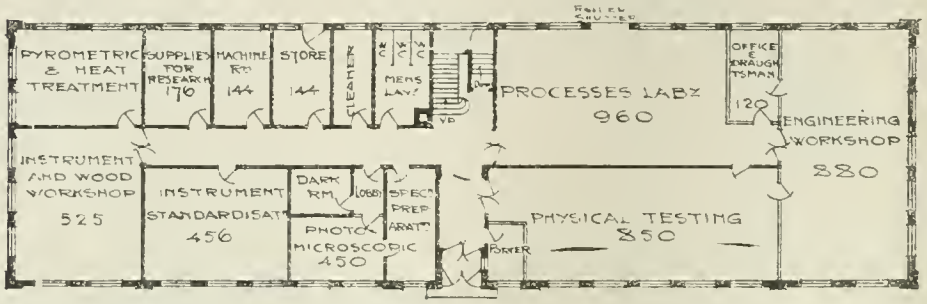
story building of 52,600 sq. ft. area is illustrated in Figs. 12 to 20 inclusive.

The choice between 2 (*a*) and 2 (*b*) will be determined principally by the amount of the land available, the character of the work to be dealt with, and the amount



FRONT ELEVATION

FIG. 9.




GROUND PLAN

FIG. 10.

FIRST FLOOR PLAN

SCALE OF FEET
0 5 0 10 20 30 40 50 60 Ft

FIG. 11.

FIGS. 9 TO 11.—Two-story research building, 12 400 sq. ft. gross floor area.

(2) For a gross floor area of about 6,000 sq. ft. up to about 12,000 sq. ft. the building may be either :—

(*a*) Single story and equivalent to the addition of two buildings of the type belonging to class (1) as illustrated in Figs. 7 and 8.

(*b*) A two-story rectangular building as illustrated in Figs. 9, 10, and 11.

(3) For a floor area exceeding 12,000 sq. ft. a multi-story building is necessary if land is scarce. A four-

of money available for initial outlay. Whilst, provided the area covered is not too large for effective supervision and inter-departmental working, it is an advantage to be wholly on the ground floor, the cost of building alone of type 2 (*a*) is about 4 to 8 per cent greater than that of the type 2 (*b*).

In considering which type will be selected, the possibility of extension must be borne in mind, and this may be done either by an addition to the older building, in the form of one or two wings or of another similar

building linked with it, or by the addition of further floors above. The first method, in either form, necessitates land in the immediate neighbourhood; the latter involves the initial provision of foundations strong enough to suit whatever superstructure is ultimately contemplated.

*Selection of fabric.* — Important factors affecting the selecting of a fabric are elimination of vibration, lighting, future extensions, fire risk, and architectural and æsthetic requirements.

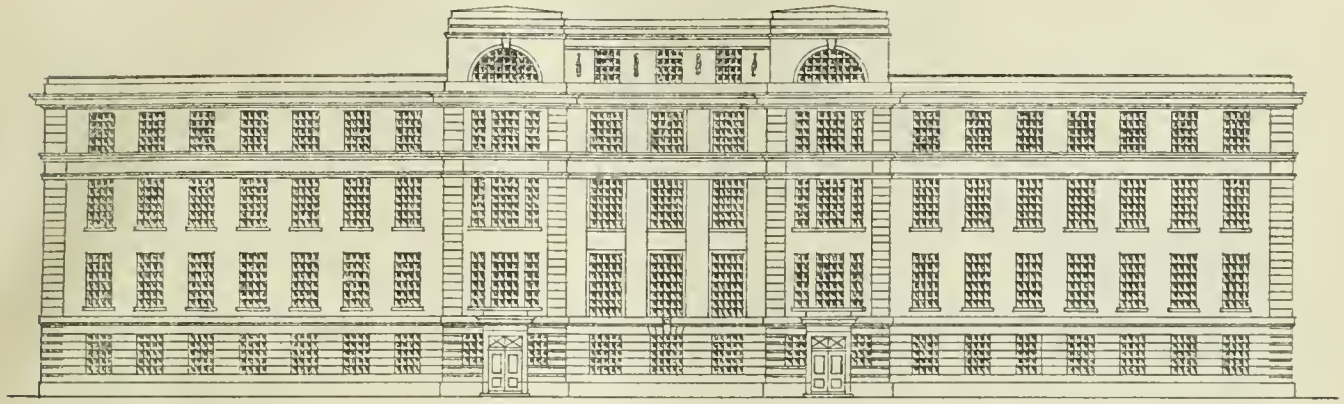
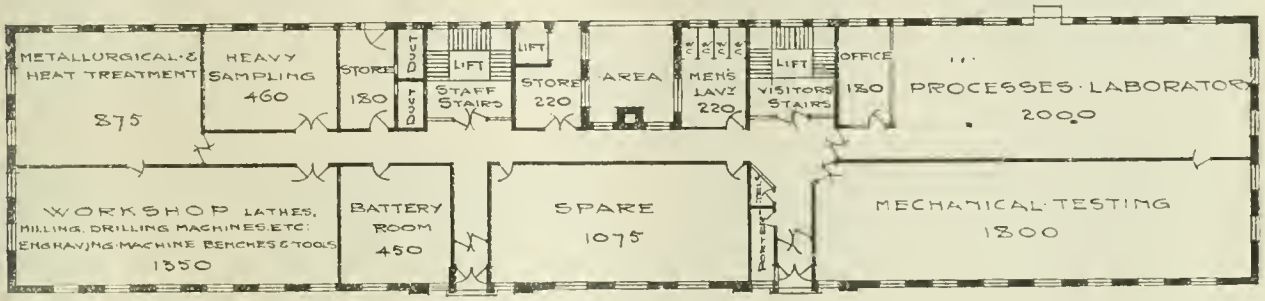
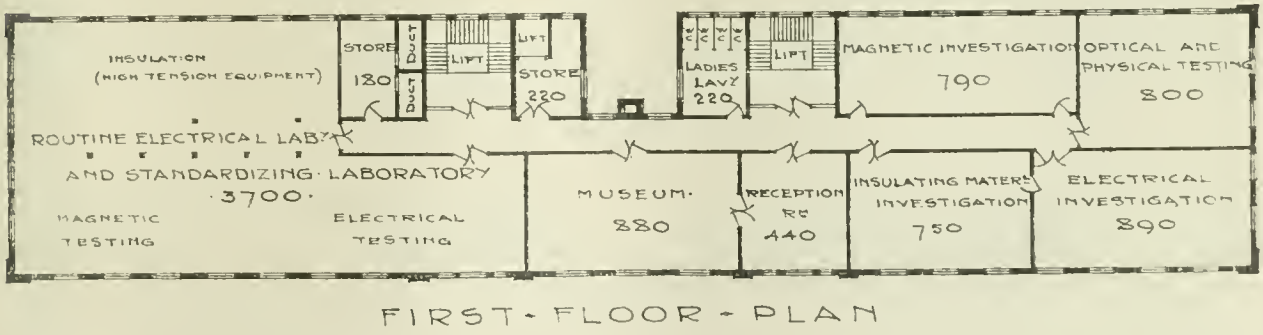



FIG. 12.




GROUND PLAN

FIG. 13.



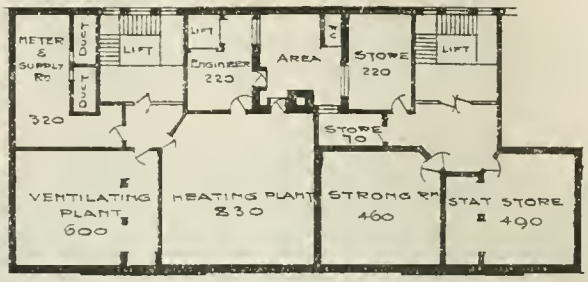

FIRST FLOOR PLAN

FIG. 14.

FIGS. 12 TO 14.—Four-story research building, 52,000 sq. ft. gross floor area.

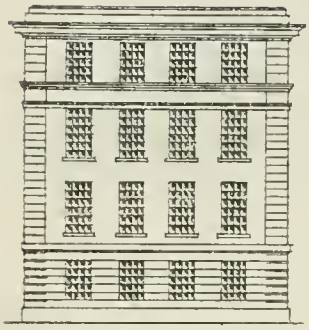
In order to exemplify the methods of design and arrangement outlined, plans of four buildings shown in Figs. 3 to 20 have been prepared, chosen of such sizes as will in each case influence the type of building adopted.

A consideration of these factors, subsequently dealt with in greater detail, in relation to various fabrics and their availability in this country suggests that for a single-floor building either a brick or reinforced concrete frame and brick fabric is to be recommended. The latter construction is cheaper than the former,



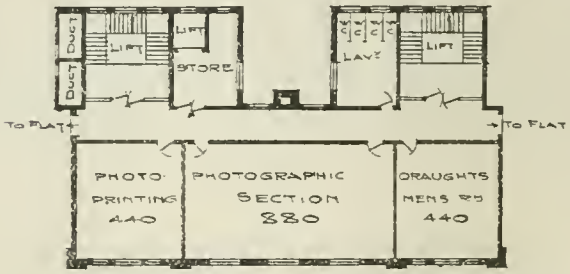

BASEMENT PLAN

Fig. 16.



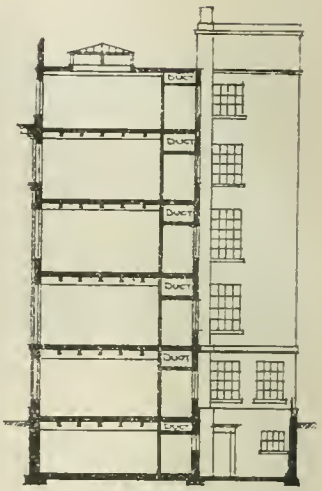
END ELEVATION

Fig. 15.



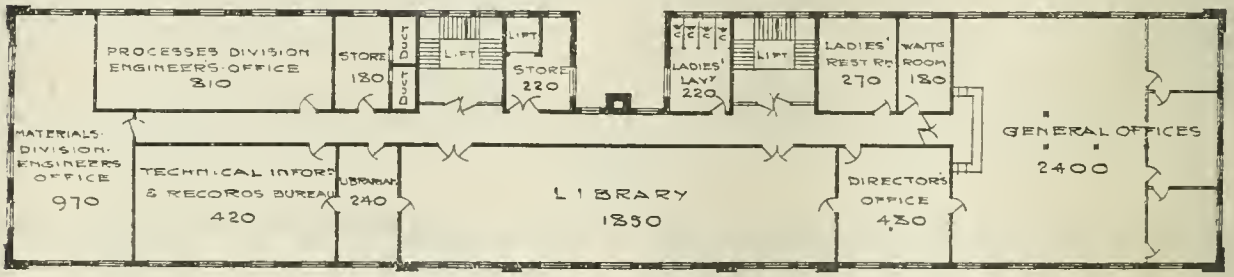

FOURTH FLOOR PLAN

Fig. 17.



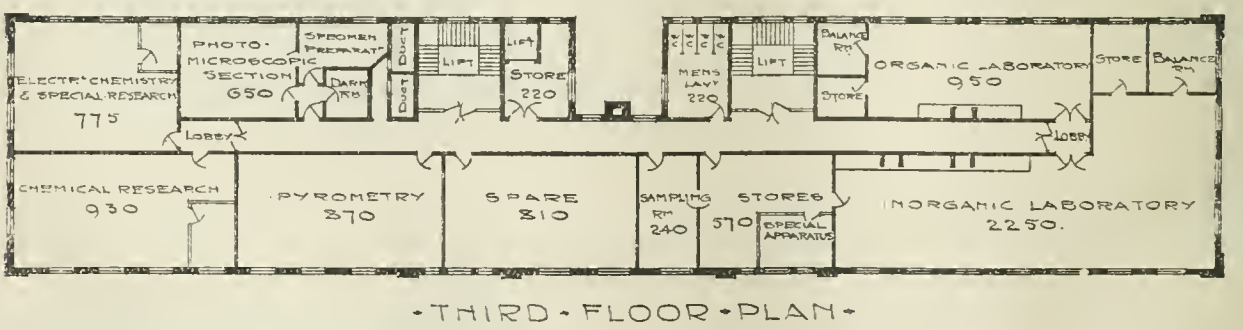

CROSS SECTION

Fig. 18.




SECOND FLOOR PLAN

Fig. 19.




THIRD FLOOR PLAN

Fig. 20.

Figs. 15 to 20.—Four-story research building, 52,000 sq. ft. gross floor area.

and usually lends itself to more effective lateral lighting. Having in view average conditions, a flat roof has much to recommend it. It readily lends itself to any partition of the building into sections; it offers no exposed parts to corrosion and hence both the first cost and maintenance cost are low; it secures the most equable temperature under external fluctuations, and it is the best form for artificial lighting. Further, a flat roof can be utilized as a proving ground, where weathering properties of materials have to be tested.

On the whole, therefore, a building in brick having a reinforced concrete frame and flat roof in the same material is recommended, and where a section requires top lighting this can be provided by a lantern or its equivalent. Many buildings, however, are provided with pitched roofs, which have some advantages with respect to natural illumination.

For two-story and multi-story buildings a reinforced concrete frame with concrete floor and roof forming a monolithic structure and with brick walls and filling, most completely satisfies such requirements as freedom from vibration and facility of extension, and at the same time will meet all ordinary architectural requirements. Such a building will also be fireproof and permits of excellent lighting.

*Elimination of vibration.*—Constant use of delicate instruments demands freedom from vibration, and its reduction depends to a large extent upon the choice of fabric. One of the most weighty arguments in favour of a reinforced concrete skeleton and flooring for two-story and multi-story buildings is that on account of its monolithic character it gives the least response to disturbing forces. All buildings, however, whatever their construction, will vibrate to some extent, and therefore where extremely sensitive apparatus is to be installed, apart from the selection of a fabric, precautions may have to be taken against vibration by providing more or less vibrationless supports for special apparatus. The matter is one which chiefly concerns internal construction.

The problem is twofold. In the first place, the building has to be screened from the disturbing forces set up by its own contained machinery. Secondly, special apparatus may require to be screened from disturbances communicated to the building from outside. The former necessitates the isolation of unbalanced machinery in reference to the main structure, and this may be done by placing all such machinery on foundations independent of the building proper. For this purpose the machinery may be housed away from the main building or situated on the ground floor or basement, preferably supported by piers built from the ground and separate from the rest of the building. In some cases it may be necessary to avoid the use of line shafting, unless it is supported directly from the ground, and to provide machines with separate and self-contained electric drives. The screening of apparatus may only require the provision of rigid tables which will not vibrate themselves, and which can be placed in positions where the vibration taken up from the building will not be serious. In this case a table top in reinforced concrete, slate, marble or like material supported from the floor by substantial piers in brick or concrete forms a satisfactory arrangement. Where more elaborate precautions are necessary, it may be essential, as indicated above, to provide specially designed supports based on the ground but entirely separate from the main structure.

An example of special supports is afforded by the laboratories of André Citroen et Cie. Here special balances, photo-microscopic and electro-magnetic apparatus are situated on the first floor, and carried on marble tables. A typical table has four indiarubber feet which rest upon the tops of two piers rising through the basement from a common foundation of concrete and brick. Each pier consists of sections in brick, concrete, and compressed cork, the latter being capped by a plate on which the indiarubber feet of the table rest.

Apart from structural features, of course, much may be done to remove vibration troubles by providing apparatus with flexible supports loaded with a sufficient mass.

*Lighting.*—Special treatment of the problem of natural lighting is required in planning a research building, on account of the close and accurate observation which is necessary.

It is important to appreciate the relative values of the intensity of illumination in the vertical and horizontal planes required for different kinds of work. Other than in special cases, it is reasonable to assume that the former is most important where apparatus is viewed more or less in the horizontal direction—a very frequent requirement — and that the latter is most valuable when surfaces are viewed from above. With the object of affording some guide as to the effect of the position of the windows upon these two components, the diagrams shown in Fig. 21 have been prepared.

It is assumed that the intensity of illumination is the same in all cases, that the light is diffused, and that the building and window extend indefinitely in the longitudinal direction. The ordinates of the full-line curves represent the intensity of direct illumination on the horizontal plane at a level of 3 ft. from the floor and on the ceilings, and the dotted curves similarly show the illumination on the vertical plane as projected from the left-hand side.

In Fig. 21 *a*, *b*, and *d* refer to rooms with flat ceilings, and *c*, *e*, *f*, and *g* to rooms having pitched roofs, and in every case the lighting is lateral or top lighting but not both. In practice, of course, the walls and ceilings reflect light; for the present purpose, however, it is not thought desirable to include the effect of this influence, as the object is to obtain for each case an approximate idea of the relative intensities of horizontal and vertical illumination. The ceiling illumination is plotted in order to afford some idea of its magnitude and influence. It would appear that lateral lighting, provided it is adequate, is to be preferred for general laboratory work, and this view is in accord with experience.

All the cases of top lighting dealt with show a high horizontal illumination and a comparatively small and unevenly distributed vertical illumination. The addition of lateral lighting would in every case consider-

ably improve the distribution. Comparing the different types of pitched roofs, the saw-tooth type appears to give the most even distribution, especially if supplemented by some lateral lighting. This type of roof with north light excludes direct sunlight, and therefore has advantages in respect of both illumination and even temperature, although its span is limited to about 30 ft. In some cases a short flat roof introduced between lighting with white ceilings and walls to secure maximum reflection.

Laboratories, libraries, and workshops require normally an intensity of illumination of 3–6 foot-candles, although for special work, for which direct local lighting units may be employed, the required intensity may be as high as 12 foot-candles, according to circumstances.

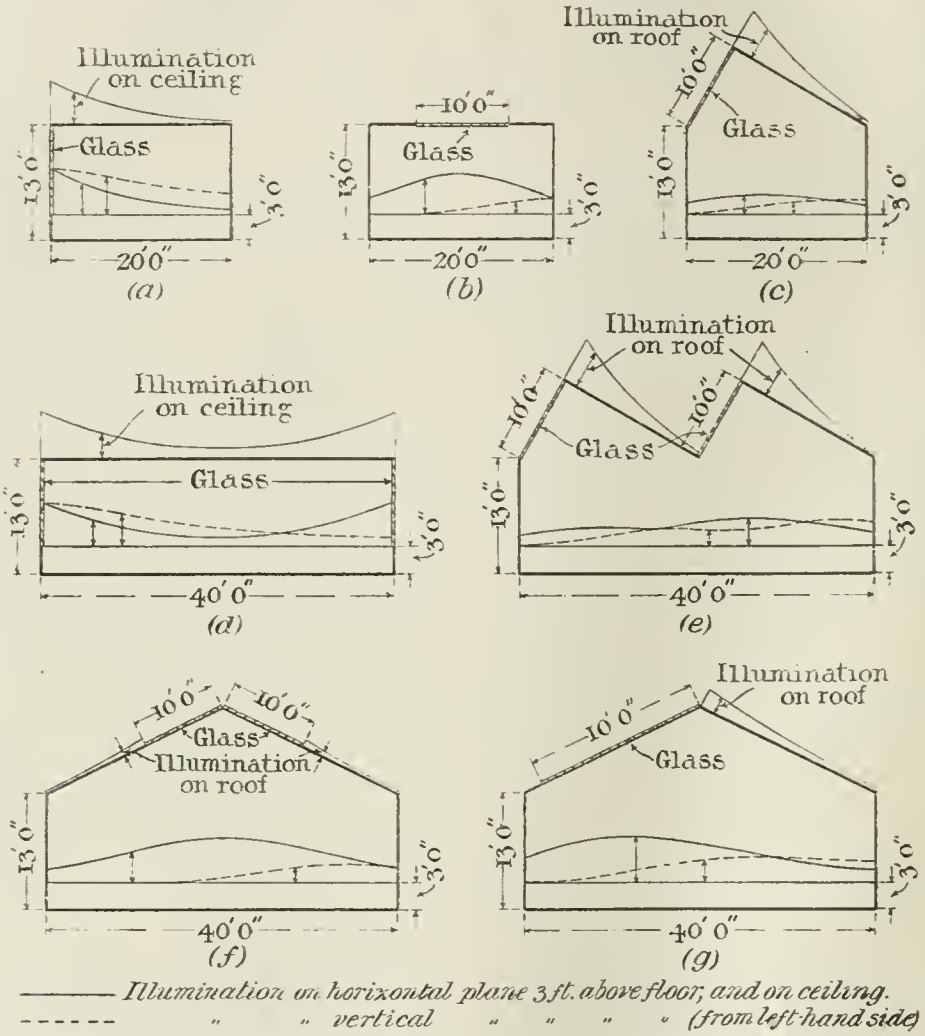



FIG. 21.—Natural illumination of research laboratories.

two consecutive spans has advantages in facilitating the erection of piping for fume cupboards.

The extent of window opening area provided in some research laboratories varies in amount from 20 to 35 per cent of the gross floor area, with an average value of about 25 per cent. The modern tendency in design of laboratories is to provide extremely liberal lateral lighting, and in this respect, as already noted, the reinforced concrete building offers advantages.

For artificial lighting, in order to reduce glare and to reproduce as far as possible the conditions of diffused daylight, it is advisable to adopt a system of indirect

A satisfactory method of determining the power, number, and spacing of lighting units for rooms, offices, and corridors, is the following:—

To supply a room with any required intensity in foot-candles in a horizontal plane, the total number of lumens required is obtained by dividing the product of room area and intensity by a coefficient of utilization, this coefficient representing the fraction of the lumens of the source which reach a horizontal plane taken 30 inches above the ground. This coefficient for the case of white ceilings and walls of high reflecting power has the approximate values: 0·4, 0·5, and 0·6 for small,

medium, and large rooms and corridors respectively, when the lighting is direct (dense glass). For semi-indirect (dense glass), and for indirect (mirrored glass) lighting these values should be decreased by 33 per cent. The total lumens thus obtained should be increased by 20 per cent for depreciation due to dust, etc.

The number of lighting units required to produce illumination of sufficient uniformity on a horizontal plane is settled by determining the mounting height (horizontal plane to light source for direct and to ceiling for indirect lighting) and utilizing the factors given in Table 1, varying with the type of unit adopted.

TABLE 1.

*Determination of Distribution of Artificial Light Sources.*

| Source of Illumination | Spacing distance / Mounting height |
|---|---|
| Prismatic or mirrored reflectors— | |
| Focussing .. .. .. .. .. | 0·75 |
| Intensive .. .. .. .. .. | 1·25 |
| Extensive.. .. .. .. .. | 2 |
| Opal bowls or domes enclosing glass units | 1·67 |
| Semi-indirect and indirect units .. .. | 1·5 |

The spacing distance having been obtained the number of units is readily found, and hence from the first calculation the size of the individual units.

When designing the lighting installation it is important to provide an adequate number of suitably placed wall plugs, and in some cases floor plugs may be advisable.

*Protection against fire.* — As far as practicable, a fireproof building should be provided, and it is admissible to equip it with the sprinkler type of automatic fire extinguishers. In addition, of course, there should be an adequate provision of hydrants, and in all rooms where there is the least possibility of fire risk chemical extinguishers should be available.

*Arrangement of sections.* — In each section of the laboratory, rooms of different sizes will be needed, and in laying out a rectangular building the larger rooms will either be placed across the full width of the building or run longitudinally, occupying approximately one-half the width of the building where there is a central corridor, and the full width in small buildings. Typical room arrangements are shown by Figs. 22, 23, and 24. Where some rooms need to be in intimate connection with others, as in the case of the balance and fume rooms in a chemical section, these may be provided as shown in Figs. 22 and 23. It will be observed that the problem of providing rooms of different sizes is facilitated by placing a longitudinal corridor somewhat away from the centre line of the building, and in the case represented by Fig. 24, it is an advantage to place any columns required for the supporting of the ceiling along the line A B.

Flat roofs and ceilings permit any arrangement of rooms to be readily made. On the other hand, a pitched roof imposes limitations which are mostly felt in the case of single-floor buildings, where all sections are together. A single span pitched roof, however, offers no difficulties in a building where the rooms extend over the full width, but where a longitudinal division is required, particularly if by a corridor, it is inconvenient, and a roof in two spans is desirable. In this case, the wall supporting the trough between the spans

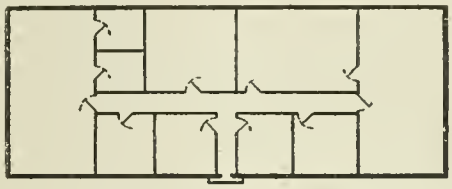


FIG. 22.—Typical arrangement of sections in laboratory.

forms one side of the corridor, and it is convenient to utilize the corridor for carrying the mains supplying water, gas, and electricity through the building.

The design of the four types of laboratories shown in Figs. 3 to 20 indicates desirable arrangements of rooms, both with respect to distribution of rooms comprising various sections and the arrangement of sections with

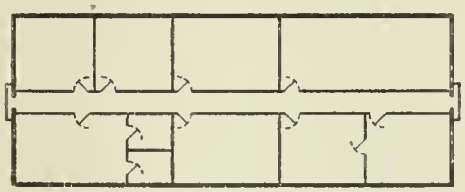


FIG. 23.—Typical arrangement of sections in laboratory.

respect to each other. Generally it will be noted that as far as possible delicate instruments and heavy machines are placed at opposite ends of the laboratory, and, where more than one floor is used, the heavy work is done on the ground floor, where furnaces are also placed. Chemical work, owing to fumes, is placed on the top floor. The offices and library

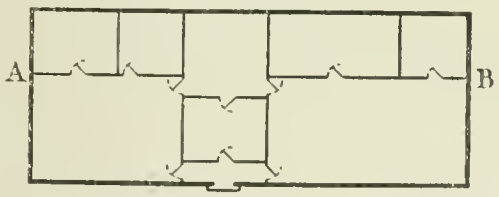



FIG. 24.—Typical arrangement of sections in laboratory.

should be adjacent and central and should be close to the director's office.

In some classes of work, as in certain chemical operations, very accurate weighing and the standardization of high-precision apparatus and instruments, variation of temperature constitutes a disturbing factor. The use of a room with double walls, in a basement if available, or failing this, with windows of northern aspect, offers advantages in this respect.

*Water, gas, and electric supplies.* — Careful attention to the provision of ducts for the conveyance of supplies to the rooms and discharge of drainage therefrom will generally save considerable subsequent trouble and annoyance.

Generally in regard to supplies, all pipes, conduits, etc., should enter the rooms close to the ceiling and be brought down to benches or other points where required. This arrangement is more satisfactory than bringing the pipes up through the floor or from troughs, and pipes should preferably run horizontally above the benches they are required to supply, rather than underneath, as is more commonly done. The main distributing pipes and cables should be arranged to supply each floor of the building; they would be situated near the ceiling and generally run along the corridor. Whenever possible, each room should be supplied by independent tappings on the main distributors.

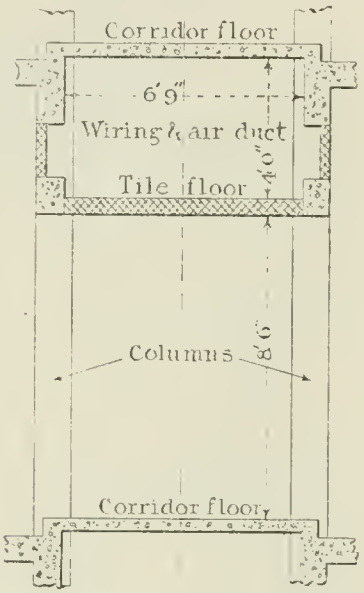



Fig. 25.—Typical duct construction.

In the case of buildings where the range of supplies is not extensive, it is satisfactory to support the main distributing pipes and cables from the ceiling by hangers. In large multi-story buildings, however, where extensive electrical work is carried on, and in which, in addition to piped supplies, a wide range of electric supply is necessary, it becomes very desirable to have special pipe and cable ducts of sufficient size to permit men to work and wherein all distributing pipes and cables may be carried. These ducts may also be employed as part of a forced ventilation system, suitable for multi-story buildings, but where this is done bitumen-covered cables should be avoided owing to fire risk. Such pipe and cable ducts are most conveniently situated above the corridors, and Fig. 25 shows a section through the duct used in the Research Building of the Westinghouse Electric and Manufacturing Company, U.S.A. When ducts of this type are to be employed a double row of columns is necessary, and the structure of the building must be arranged accordingly.

Research requiring electric currents of large magnitude, as electric furnace work, will generally be arranged on the ground floor or basement, and it is convenient to have a suitable system of ducts cut in the floors and covered by plating, in which cables may be placed. Otherwise, it is desirable to keep the floors of research buildings as free from ducts and channels as possible. In the chemical and metallurgical laboratories where special drainage facilities are necessary, it is also desirable to arrange for sinks, etc., to discharge by open-ended pipes into receptacles let into the floor and connected to the acid drains. These should be easily opened up for examination.

The building should be equipped with soil and acid drains, and it is better for the two systems to remain separate within the building and discharge through traps into a common sewer outside. Where objections are likely to be taken to the discharge of acids into the common sewers, a special treatment bed should be provided, when the necessary neutralization can be effected.

Generally, all rooms in a large building will be piped for hot and cold water and gas. In addition, it may be necessary to pipe the whole, or at any rate a part of the building with some or all of the following supplies, namely, gas raised in pressure by a compressor to about 4 inches of water: compressed air at about 50 lb. per square inch above atmospheric pressure; distilled water and an electric supply of suitable voltage and frequency. For special purposes oxygen and hydrogen may be supplied.

As an example of the range of supplies regarded as necessary for a large research organization, reference may be made to the Research Building of the General Electric Company, U.S.A. This building is piped throughout with the following supplies, namely:—

(*a*) City and river water.
(*b*) Distilled water delivered by gravity.
(*c*) Illuminating gas at both ordinary and high pressures.
(*d*) Hydrogen.
(*e*) Oxygen.
(*f*) Compressed air.
(*g*) Vacuum for experimental purposes.
(*h*) Vacuum for cleaning purposes.
(*i*) High pressure steam.
(*j*) Electric supply as follows:—

From external source:—d.c. three-wire 250 volts; three-phase, 40 cycles, 120 volts.
From Research Building power plant a supply up to 12,000 amperes, voltages up to 200,000, and frequencies from 25 to 2,000 cycles.

*Heating and ventilation.* — A building for research purposes does not introduce any special requirements in the matter of artificial heating. In all cases the low-pressure hot-water system can be recommended on the grounds of its efficiency and greater freedom from trouble than high-pressure and steam-operated systems. In spite of theoretical objections hot-water pipes carried round a room near the ceiling give very good results. If steam radiators are used their usual position under

the windows frequently interferes with the placing of bench fixtures.

For the ordinary ventilation of the building no special provision is needed in single and two-floor buildings other than is provided by the windows, but in the case of multi-floor buildings forced ventilation is recommended, and, as already noted, where a special cable and pipe duct is provided a portion of it may be utilized for distributing the air supply through the building. Special local ventilation will, of course, be needed in the chemical and metallurgical laboratories, where fumes are produced, and usually no difficulty will be experienced in securing effective extraction by means of fans.

*Internal finish.* — Finish and decoration of the interior will be decided by individual taste and the expenditure permissible for the purpose. Generally, however, for most sections, excluding offices and library, it is recommended that the walls have glazed tiles or bricks of a pleasing shade to a height of about 4 ft. 6 in. from the ground, and the remainder of the walls to the ceiling be distempered in a light colour having good light-reflecting properties.

White glazed bricks or tiles extending to the ceiling are recommended for the chemical laboratory. Partitions should be of hollow tile or wood to a height of 4 ft. 6 in. from the ground and glazed above to the ceiling.

For floors, hard wood blocks treated and laid on concrete, tiles and special compositions, have proved satisfactory, although in regard to the latter only well-tried and approved makes capable of meeting the conditions in a research building should be considered. Some compositions are noisy and cold and easily crack. Where a battery room is installed, an asphalt floor is recommended. Rounded corners are recommended for the junction of the walls and partitions with the floors, these preventing the accumulation of dust.

*Furniture.* — Laboratory furniture in the various sections does not call for special comment, except possibly in the case of the chemical section.

There is no doubt that equipment such as benches, fume cupboards, and hoods found satisfactory for technical instruction purposes has exerted an undue influence upon the design commonly employed for industrial work. The conditions in the two cases, however, are very different. In technical colleges students have to be accommodated at a comparatively high density for short periods. This necessitates a large stock of minor equipment which must be immediately available if time is not to be lost unnecessarily in fitting up apparatus. Hence the evolution of the usual type of bench with its numerous drawers and cupboards. The demand made upon the fume chamber is generally not heavy, with the result that this fixture is often small and the arrangements for fume extraction weak. In the works laboratory the floor space per employee is much larger, and the large majority of the apparatus not actually in use is best kept in a store and the accumulation of drawers and cupboards becomes unnecessary. Fume chambers have at times to cope with heavy rushes of urgent work, and therefore they must be of ample capacity and of especially durable construction. The draught arrangements must obviously be both powerful and positive.

One or two drawers per bench meet all requirements. The bench top should consist of a material capable of resisting acids and of being readily cleaned. In a number of recent American research buildings, alberene — a soft talc-like stone — is largely employed for bench tops and also in constructing fume chambers and hoods. Other suitable materials are glazed tiles and rough plate-glass, but where such materials are employed it is advisable to make use of soft sheeting to prevent the breakage of delicate glassware. The bench top should be entirely free from all projections, such as gas cocks, etc., and hence all pipes conveying supplies should run above the bench. The advantage of standardization may be secured by the adoption of a unit-type bench which can be built up to any length by the addition of units.

Referring to fume-chamber construction, a form found satisfactory consists of wired rough plate glass in steel framing and windows of transparent wired plate glass set in steel sashes, the whole of the steel work being protected by heavy coats of a resistant paint. In the alberene stone fume-chambers, framing is unnecessary and fixed windows may be cemented directly on the stone. Wood is used for the framing of the movable windows. All supplies to the chamber should, of course, be controlled by cocks and valves placed outside, and there should be an adequate provision of hot-plates for accelerating operations.

The ventilation of fume chambers, hoods, etc., may be assisted by a fan. This may be supplemented or replaced by steam or compressed-air induction jets situated at the entrance to the flues, or a jet above the chamber working on the ejector principle.

*Costs.*—Pre-war costs are more trustworthy for estimating purposes than current costs based on changing and inflated prices. They represent a standard by means of which costs for other times may be determined and in the following figures pre-war conditions are assumed.

Costs may conveniently be considered under the following heads :—

(*a*) Building.
(*b*) Furniture.
(*c*) Apparatus and equipment.
(*d*) Maintenance, including salaries.

(*a*) *Buildings.*—Average pre-war costs for four types of buildings for different fabrics are represented in Table 2. Areas approximating to those given in the table may be obtained by interpolation. For convenience in comparison, the areas, which are gross, are given in round figures, slightly different from the actual areas shown in Figs. 3 to 20.

All buildings are designed to be of fire-resisting construction, and Table 2 includes provision for heating, ventilation, artificial lighting, pipes, ducts, and drains.

To obtain an approximate estimate of the cost of a structure, multiply the floor area by 7·4 and then by the figure in the table and divide by 1,000. Thus

6,000 sq. ft. building of Class 1 would cost approximately $6 \times 7{\cdot}4 \times 100 = £4,440$.

(*b*) *Furniture.*—The amount of money which can be spent on furnishing any given laboratory will vary considerably according to the nature, quality, and finish of the material used. But beyond a certain point no gain, save perhaps improved appearance, is to be obtained by increased expenditure. Table 3 gives particulars in respect of adequate and satisfactory furniture of average construction and finish, such as is commonly employed for laboratory purposes. The figures include cost of installation.

(*c*) *Apparatus.*—Careful estimates have been made up of such costs for a number of well-designed and equipped industrial laboratories on a pre-war basis, although some of these have been equipped during the war, the figures being given in Table 3. These figures for convenience are expressed per square foot of active floor area, since the cost is given for each section.

TABLE 3.

*Cost of Furniture and Equipment for Different Sections*

| Section | Average Cost in £'s per Square Foot of Active Floor Area | | |
|---|---|---|---|
| | Furniture | Apparatus | Furniture and Apparatus |
| Physical testing .. | 0·1 | 1·75 | 1·85 |
| Workshop .. .. | Small | 1·25 | 1·25 |
| Chemical* .. .. | 0·3 | 0·6 | 0·9 |
| Photomicrographic† .. | 0·25 | 0·4 | 0·65 |
| Pyrometric .. .. | 0·2 | 0·5 | 0·7 |
| Metallurgical and heat treatment .. .. | 0·05 | 0·5 | 0·55 |
| Electrical and magnetic | 0·2 | 0·8 | 1·0 |
| Office and library .. | 0·5 | — | 0·5 |

* Includes fume room, balance-room, office, and stores.
† Includes dark room.

(*d*) *Maintenance.*

*Salaries.*—It is difficult to give figures for salaries, since they will necessarily vary in different laboratories. On a pre-war basis, however, the average salary for the whole range of workers necessary to secure efficient working may for the purpose of guidance be taken as £200 per annum per worker.

*Running costs, depreciation and obsolescence.*—An estimate of maintenance costs of laboratories apart from salaries is difficult to make at present, but it may be roughly taken to be two-thirds of the amount spent on salaries. The maintenance costs on this basis are included in Table 4.

TABLE 2.

*Cost of Buildings of Different Areas and Fabrics.**

| Class | Description of Building | Type 1. 6,000 sq. ft. Single Story | Type 2A. 12,000 sq. ft. Single Story | Type 2B. 12,000 sq. ft. Two Story | Type 3. 52,000 sq. ft. Four Story |
|---|---|---|---|---|---|
| 1 | Brick and steel frame with stone dressings and architectural finish | 100 | 96 | 92 | 88 |
| 2 | Reinforced concrete with stone dressings and architectural finish | 99 | 94 | 87 | 83 |
| 3 | Brick and steel frame, plain finish .. .. .. | 92 | 88 | 83 | 77 |
| 4 | Reinforced concrete, plain finish .. .. .. | 90 | 86 | 78 | 74 |

* Prices are based on pre-war conditions.

TABLE 4.

*Capital Outlay and Maintenance Costs.*

| | Cost per 1,000 sq. ft. Gross Floor Area | | Cost per Employee (occupying 225 sq. ft. Gross Floor Area) | |
|---|---|---|---|---|
| *Capital Outlay*— | £ | £ | £ | £ |
| Building .. .. | | 600 | | 135 |
| Furniture .. .. | 175 | | 40 | |
| Apparatus .. .. | 650 | | 150 | |
| | | 825 | | 190 |
| Total capital outlay .. | | £1,425 | | £325 |
| *Maintenance Cost per Annum*— | £ | | £ | |
| Salaries .. .. | 875 | | 200 | |
| Maintenance .. .. | 575 | | 130 | |
| Total maintenance costs | £1,450 | | £330 | |

Estimates are also difficult to make for depreciation and obsolescence. For research work, equipment is generally obtained to meet requirements of work in hand, and at the conclusion of the work the equipment may be virtually discarded, the figure of obsolescence being accordingly high. For routine work the figure suggested by experience depends very largely on the care which is taken of apparatus and the degree of experience possessed by those using it. Breakages are generally high where inexperienced workers, such

as many juniors and women introduced during the war, are engaged, and prevailing high and fluctuating costs militate further against any special figures being given which would be of value.

The high proportion of the total cost of maintenance which is covered by salaries renders the amount to be set aside for interest on capital, depreciation, and obsolescence relatively small by comparison.

*Total costs.*—By combining the figures given by Tables 2 and 4, costs of the four types of buildings of the sizes given, referred to in the former table, can be obtained. Table 5 shows the costs for a structure in reinforced concrete having plain finish.

Table 5.

*Capital Outlay and Maintenance Costs for Laboratories Illustrated.*

| Cost of— | 6,000 sq. ft. | 12,000 sq. ft. | | 52,000 sq. ft. |
|---|---|---|---|---|
| | Type 1. Single Story | Type 2A. Single Story | Type 2B. Single Story | Type 3. Multi-Story |
| | £ | £ | £ | £ |
| Building .. .. .. .. .. .. .. | 4,000 | 7,640 | 6,930 | 28,500 |
| Furniture .. .. .. .. .. .. .. | 1,050 | 2,100 | 2,100 | 9,100 |
| Apparatus .. .. .. .. .. .. .. | 3,900 | 7,800 | 7,800 | 33,800 |
| Total capital outlay, excluding land .. .. .. | 8,950 | 17,540 | 16,830 | 71,400 |
| Total annual maintenance, including salaries .. .. | 8,700 | 17,400 | 17,400 | 75,500 |

Since space required per worker in a research building is most advantageously expressed in square feet, it has been convenient to give costs of building per square foot rather than per cubic foot. If the latter form is preferred, costs may be readily worked out from the plans. The dimensions should be taken to include the outer walls, whereas for the cost on a basis of area the dimensions inside the outer walls are taken. Heights for the five buildings illustrated, including the distance below ground to the top of the foundation, should be taken as 15 ft., 15 ft., 15 ft., 31 ft., and 58 ft. respectively. In determining present-day costs it should be remembered that different building materials have not increased in price to the same extent.

The important facts brought out by Tables 4 and 5, particularly the latter, are that, excluding the cost of land, the cost of the building for the fabric assumed is somewhat less than half the total capital outlay. Further, the normal annual maintenance cost is about equal to the capital outlay. These relations—which are confirmed by published data relating to American laboratories—show very clearly that the cost of the building is of secondary importance, and therefore liberality should be shown in providing a building of ample size to cope with expansion of work. Also, in view of the cost of maintenance, of which the greater part is taken up by salaries, given a good staff it is altogether false economy to endeavour to limit expenditure on the equipment; and further, every assistance in the way of illumination, ventilation, and good working conditions incident to the highest efficiency is a real economy.

## Conclusions.

No hard and fast rule can be laid down as to the amount of money that should be expended on research. Every undertaking must be considered on its own merits and research expenditure based on the economic needs of the moment and the probable requirements of the future. In many cases it is the impoverished industry which stands in the greatest need of research. Similarly, the small concern, though it may not be able to afford expensive research facilities, can make considerable use of those afforded by universities, national institutions, and private or commercial laboratories. Then, again, the wealthy firm or prosperous industry can maintain an unassailable position through improving by research its methods of production, this being ultimately the only effective method of securing monopoly.

It is an economic error to assume that the best method of increasing profits is, through trade combinations or other means of protection, to increase selling price. A much more logical method is to bring about the difference between manufacturing cost and selling price by reducing the cost of manufacture, and it is in this connection that the possibilities of research are unlimited.

Apart from its value in assisting economic manufacture, the advertising value of research should not be overlooked. The knowledge that a manufacturing firm employs scientific methods establishes in the public mind a feeling of confidence in the firm's products. Similarly, this may be a by no means negligible factor in favourably influencing investors.

It is to be hoped that firms undertaking research on a large scale will adopt a broad-minded policy in regard to the publication of a great deal of the results of their work. The tendency towards secrecy on the part of most British firms has been weakened to a considerable extent during war time, when many otherwise rival firms have been engaged upon similar kinds of new work, in which each firm could benefit by exchanging its experience with other firms engaged in the same production. This exchange of experience and information is of the greatest importance in keeping all sections of an industry up to date, and in this way an industry becomes much more potent in inter-

national competition, and at the same time individual firms through differences in organization are no less able to compete among themselves. Moreover, the preparation of work for publication and discussion is of great educational value to a research worker.

In staffing a research organization, the highest economy is secured by obtaining the very best brains in the various positions, and posts in the research department should be looked upon as those most highly prized in an industrial organization.

It is to be hoped that the great industrial organizations having well-established research facilities will extend their hospitality freely to those workers in universities and elsewhere to conduct important investigations which they have leisure but not equipment to undertake, and that considerable freedom of interchange of ideas and experience with other research organizations will be practised.

The author desires to acknowledge his grateful thanks to Mr. J. G. Pearce, of the British Westinghouse Company's Research Department, and to Mr. R. W. Bailey, for untiring assistance in the investigation and examination of details regarding a large number of existing laboratories,' and in preparing much of the data on which the paper is based, and to Mr. E. G. W. Sonster, A.R.I.B.A., for preparing architectural drawings and for criticism of and assistance in connection with architectural details.

## Discussion before The Institution, 23 January, 1919.

**Mr. C. C. Paterson**: Although the author has described in his paper what has been done in other countries, he has not, however, dealt with what this country has done in the way of industrial research. Whilst it is of the greatest value to have before us the full details of American progress in this direction, it is well to remember that this country also has its industrial research laboratories and will soon have many more. There is one point in connection with internal laboratory organization which I should like to mention first of all. The author rightly says that for the senior posts in the laboratory one must get men who have high qualifications of all kinds. To my mind, however, and to the minds of some others who have seen the time of such men wasted, the following problem arises: How are we to ensure that those men who have special qualifications in research will be kept on research and will not be preoccupied with the running of their sections and doing the hack work of administration which, after all, is very easy compared with the real work of research? The problem may seem simple, but I have not yet seen a complete solution. If there are ways of getting over this difficulty—and I think there ought to be—it can only be by very loyal co-operation between the men concerned. Then the author raises the question of the scope of the work which should be permitted in an industrial research laboratory, and he seems inclined to think it should be restricted to industrial research. That depends on how one interprets the term "industrial research," but in any case I think a great deal of latitude ought to be allowed to a research worker if he seems sometimes to deviate from the rigid industrial path. Apart from other considerations, there must be in a research laboratory a real spirit of research, and one cannot foster this by constant limitations. Turning to the question that he mentions of works discipline and works hours, I am not at all sure that we can expect exactly the same behaviour and exactly the same organization as regards staff working in a research laboratory as we can in the works. The hours worked by the research men in a laboratory must depend partly upon the number of meetings of scientific societies which they should attend and the various other activities necessary if they are to keep in touch with what is going on elsewhere. With regard to the question of holidays and leave, is it expected that a man who puts all his energies into research can recover in a fortnight's holiday the amount of energy which he has given up in 12 months' work? There may be exceptional people who can do so, but the amount of leave which a good research worker must have is not a question of the minimum that we are willing to give him, but of the amount that will keep him in a state of first-class efficiency for the very difficult and exacting work which he has to do. I think the details of the construction of the works laboratories which the author has referred to are open to some criticism. He seems to suggest, without giving any reasons, that it is most undesirable to have a laboratory which is larger than 12,000 square feet superficial area in a single-story building. I strongly differ from that point of view, and I cannot see the advantage, if we have plenty of land, of going up to two, three, or four floors if we can keep on the ground floor. A ground-floor building is an enormous advantage from the point of view of extensions. Such buildings as are illustrated in the paper can only be extended with the greatest difficulty. If, however, we have a building on the ground floor which is largely roof-lighted, we can extend in almost every direction. Also, from the point of lighting, I am a very strong advocate of the saw-tooth roof, or some construction of that kind, combined with a certain amount of lateral lighting. An exclusively lateral-lighted building does not give real efficiency in the utilization of a room, whereas in a north-lighted building we can use almost every corner of the room for any experiment and get good lighting everywhere. The author suggests that the laboratory must have workshop facilities. Unfortunately, a workshop is a very expensive but a most vital part of research laboratory organization, and the efficiency of a research laboratory depends almost entirely, in my view, on the workshop facilities which are available. I do not think 10 to 15 per cent of the total working expenses of the laboratory is too much to put aside for proper workshop equipment, because every research worker must be able to have at his beck and call mechanics either in wood or metal to help in his work, and it is very false economy to try to restrict this. With regard to the question of the

library, I know of one laboratory in which the library is on the second floor of the building, where a man can go and read in perfect tranquillity. It is a very nice and very beautiful library but very little used, and it always seems to me that a research laboratory library ought to be in a very central place to which a man cannot help going. I would even sacrifice it to the extent of combining it with the canteen if it only ensured that the men would go into the library and use it. The whole idea of a librarian very often seems to be to see that no book or periodical ever gets lost, when it would be worth while losing many periodicals if one could only make sure that they were read and used. On the question of costs I should like to say that the figures the author gives are most useful, but they are subject to modification as the result of the events of the past four years. Up to the present the cost of buildings has increased a good deal more than salaries. The cost of the equipment has not, I think, gone up quite as much as the buildings. I should be sorry to have to consider that the annual running expenses of a laboratory are equal to the cost of the buildings and their equipment, as prices stand at the present time.

**Dr. E. P. Hedley:** Ever since I read the author's monograph published by the Privy Council, I have had an unbounded envy for the country which he inspected and which could spend so much money on research. I wish that this country would take a lesson from America and spend more money than we are doing; after all, it is not very much compared with what the United States spend. The housing of routine and research work in the same building, which the author suggests, is very wise, not only for the reasons given by him, namely, the bringing together of routine workers and research men, but also because it generally leads to economy of research men's time in the following way:—In the working out of an alloy, for instance, the physical-chemist or the metallurgist would bring together the likely metals, melt them up, heat-treat them, and produce his alloy, and then hand over the alloy to the routine men who, being quicker at their work than the casual experimenter, can put the alloy through the various physical, mechanical, and electrical tests which the alloy is required to stand, while in the meantime the research man is going on with the examination of the series which it is intended to examine. All research work which involves much routine work, be it chemical analysis, mechanical or physical tests, can be carried out in this manner, and such team work is more economical from the firm's point of view than any other, and, when sympathetically administered, leads to the introduction into the laboratory of the true scientific spirit by stimulating interest and mental competition among the body of workers. But the author is on much more dangerous ground when he advocates the use of the laboratory as a training ground for positions in the works. Positions in the laboratory ought to be sufficiently attractive to retain men within the laboratory; for the value of a good research man grows with accumulated experience, and the effect on the atmosphere of a laboratory would be disastrous were the idea to creep into the minds of the workers that the works offer better prospect for advancement. That brings me to another very important point, one about which the author has said little or nothing, namely, the payment of research men. He mentions a pre-war figure of £200 per annum as a sufficiently high average to secure adequate and efficient working. I think that is much too low, unless it be as a commencing salary. To-day that would probably be worth £400 a year. The author admits that we want university men in industry, and that the supply for a long time to come will be far below the demand. If these well-trained university men are to be attracted to industry, something really worth while must be held out to them. The low salaries paid to scientific men in the past have been one of the causes of our industrial backwardness, because our best brains have gone into more lucrative professions such as the law. The adequate payment of research men is not, however, a simple matter, for the following reason: research must be made so attractive that men will not look upon positions in the works, such as the heads of departments, etc., with eyes of envy. The heads of departments in many works receive a living salary, coupled with a percentage on their output, usually about 10 per cent. How, then, is this attraction to be counteracted in the laboratory? If a new process when worked out in the research laboratory were the work of one man, it would be an easy matter to give him a bonus on the output for a few years. But the working out of an idea is very seldom the work of one man; and, as I have pointed out already, team work is the most economical from the firm's point of view and the most expeditious way of getting results, as well as the most stimulating method from the research men's point of view. Moreover, allowing a man to work individually with a bonus in view usually develops several vices, such as a tendency to be secretive, to refuse co-operation, and therefore vitiate the value of team work; and if a man dies or leaves the works, it is very difficult indeed to take up his research work if he has been working individually. The most satisfactory way, in my opinion, is to pay a good salary and give a bonus to the laboratory to be divided among the workers in proportion to their salaries; and especially satisfactory individual work can be recognized by a substantial increase in a man's salary, thus retaining his work for the future benefit of the firm.

**Mr. A. S. Barnes:** I am one of those who believe that the future of civilization depends upon the widening spread and the deepening hold of the scientific habit of mind. Our present civilization is the outcome of the age-long action and reaction of mind on matter and of mind on mind. On the material side, that is the side of the action of mind on matter, the man of science and the engineer have played a predominant part; and I venture to think that in the future the electrical engineer will play a part of increasing importance. On the ethical and spiritual side, that is to say, the side of the action of mind on mind, I think the value of science is higher and more permanent than any material good which the advancement of science may bring us, great though this may be. In the past we have thought of science as being about

and far removed from the workaday world; to-night we are here to discuss the union of science and industry. I have no doubt that this union will be a fruitful one on the material side; that the commerce of our country will be enlarged; that the amenities of life will be increased, and the conditions of our industrial workers will be improved, and that the man of science himself will profit by his experience of contact with business methods. This union of science and industry must include not only the spirit and methods of science but what is termed "pure science" itself. On page 154 the author almost apologizes for the inclusion of pure science within the purview of a works research organization, and he seeks to justify its inclusion by the fact that the new knowledge produced will probably find a speedy application in industry. Now there are two well-known methods of attacking a problem in research; one is known as the "cut-and-try" method, and is sufficiently indicated by its name: the other consists in attempting to get as directly as possible at the root of the matter in hand and to understand it. There are undoubtedly situations in which we are obliged to apply the cut-and-try method, and we have to trust to instinct and to luck to bring us successful results. But, at the long last, in most cases the fundamental method is the quicker, the better, and the cheaper. Most of the matters set out in the schedule on page 154 as being within the ambit of the works research organization have their roots in pure science, and if the fundamental method of attack is to be pursued it follows that pure science is necessarily included in the purview of a research organization. I feel that the most important thing we can do is to preserve the high ideals of science in its union with industry; we must lift up industry to the level of science rather than pull science down, if I may say so without offence, to the level of industry. Whatever be the aim of research, whether it be a desire to extend the boundaries of knowledge, or the achievement of a utilitarian purpose, the scientific habit of mind and the ideals of science must be preserved if work of permanent value is to be done. The creation and maintenance in industry of an atmosphere and environment in which the spirit of science can flourish is of fundamental importance. In industrial research, organization, direction, and co-ordination are necessary, but let the restrictions be a minimum and let free play be given to the all-important vitalizing spirit.

**Sir Robert Hadfield, Bart.:** I have myself seen many of the laboratories to which the author refers, and I can fully confirm all he says with regard to the very great importance of keeping up to the standard in regard to what we do in this country. In my opinion, however, this country has not been very much behindhand. We Britishers are very practical. We may not be lavish in our expenditure, but, as this war has shown, we get there all the same. I do think that we should not run down what our country has done in the past, because in my opinion it is bad for us; it implies that we cannot rely upon ourselves. Whilst a pessimistic attitude is sometimes desirable, surely it is not so at the present time. I affirm that we can rely upon ourselves, and we have done it in the past, although we have been somewhat deficient in certain lines of work. If we cannot admire the "kultur" of Germany, generally, we can at any rate admire the magnificent research laboratory of Krupp's at Essen, and we have to think of the encouragement given in that country to research and of its great effect on the future. We may find fault, very rightly, with German methods of carrying on business in commercial matters, but we can still learn from the enemy in the instance to which I have referred. I was through the Essen laboratory the year before the war, and Krupp presented me with a complete catalogue of information regarding its construction on which his firm had spent no less than £180,000. I was also there six or seven years before that new laboratory was put up, and could therefore see the enormous strides that they had made. During my last visit in 1913 there was no attempt to hide anything. I went round the works and was shown every nook and corner in the research laboratory and also many of the other departments. I had a translation prepared of the information presented with regard to the research laboratory; in it every room of the laboratory is described, and if it will be of any use to place these plans at the service of any member of the Institution I shall be pleased to do so. An ounce of practice is worth a good deal of theory, and I may say that during the war we have designed a research laboratory for my company's works in Sheffield which would have been carried into effect but for the fact that it has been impossible to get supplies. I have brought with me to-night a model of that laboratory to illustrate our idea of what a research laboratory should be. It was designed to deal with the particular line of work in which my firm is chiefly interested, namely, ferrous-metallurgy. As will be seen, the model is made in such a way that it can be taken to pieces, floor by floor. There are three floors altogether. On the top floor we have the whole of the chemical laboratories divided into larger and smaller rooms, general laboratory, a balance room, and a number of smaller rooms for each of the special lines of work which have to be carried on. The author has given some admirable plans of a somewhat similar construction. On the next floor we have the physical laboratory, and that again is divided into a number of larger and smaller rooms according to the class of work that has to be done, such as magnetic observation. Then there are all kinds of small drawing offices and other rooms of that kind. On that floor we have reserved rather a large room for something which perhaps has nothing whatever to do with research or science, namely, a room for the cinema. The ground floor of the building is devoted to mechanical testing of all kinds, fatigue testing, and general stores. When I was going through the Krupp laboratory, Dr. Ehrensberger, one of the directors, took me into a very interesting portion of their laboratory; he pressed a button which lowered a screen at the window so that all the light was immediately excluded, and within a few seconds various photo-micrographs were thrown on the screen. The model I present to-night shows our point of view with regard to the construction of a research laboratory for special work. I hope some of the members present

will find this of service. In addition to the laboratory proper, we have a rather large technical workshop in which we intend to carry out practical work such as that to which the author has referred—melting and pouring of metals, and a small steam hammer for forging the steel for small specimens. I myself should like to see this technical workshop still further enlarged, but exigencies of space would not allow of this. Whilst a laboratory of this kind does not want to mix up the practical with the scientific side, that is to combine them in one and the same building, nevertheless a technical workshop added to the research laboratory must be of considerable service. For example, in it the various specimens would be prepared, or when new material is being tested this could be done on the spot near the laboratory. This would all mean a saving of time, which means money, and more work done.

**Dr. C. C. Garrard:** I should like to refer to the association which the author has made between the works laboratory, the research department, and the development department. To my mind it is not desirable that the functions of these three should be mixed up, the chief reason being that the research worker should have his head quite free from routine matters in order to attend to the work with which he may at the moment be occupied. When one thinks of the kind of work which the works laboratory has to do—such, for instance, as 500,000 chemical analyses per year, as described by the author—it is quite evident that such an organization entails the employment of a chief who must give his whole attention to matters of routine in order to get the work done without excessive cost. Such routine is the antithesis of research work. Also I think that each of these three departments entails a different scheme of organization. The works laboratory is a part of the production department: it is one of the methods of control whereby the management controls the products of the factory. It is just as much a part of the production department as is the costing department. By means of the latter the management controls the financial aspect of manufacture, and by means of the works laboratory it controls the quality of material. On the other hand, development work is not really research; it should be the concern of a special experimental department of the factory. Development work must be departmentalized on account of its specialized character. For example, take the works with which the author is associated, the British Westinghouse Company. It is evident that the man who has to develop dynamo-electric machinery has to have an altogether different equipment from the man who has to develop, say, electricity meters. The development department should be an adjunct of the works, and a large concern which has specialized works should attach to each of those works a development department whose duty it would be to develop the products from day to day. To make my point clearer, let us consider the genesis of a new article. First of all we have the scientific principle which is evolved, say, by a worker in a scientific laboratory. He discovers a principle. Take, for example, the recent development of a new form of lightning arrester, the oxide-film arrester. The fundamental principle connected with that is the physical fact that certain salts, which are conductors, become non-conductors when heated. The research laboratory, according to my view, takes this scientific principle and develops a practicable article from it. There is, however, a very great difference between that and a product which can be catalogued and sold. This is very often overlooked. The research worker will make an article which will act as a lightning arrester, but it is then very far from being one which a manufacturing firm can sell as a standard article. It is this standardization work which the development department should do. I think, therefore, that the research department should stand by itself: it should be distinct from both the works laboratory and the development department, and should concern itself with purely industrial research. I should like to make one criticism in regard to the costs of buildings in the paper, on page 168. In my opinion they are very high. They work out, I think, at 14s. 9d. a superficial foot, pre-war cost. Assuming each floor to be 15 ft. high, this represents a shilling per cubic foot, pre-war cost, corresponding, at the present time, to about 2s. a cubic foot. This seems to me at least 100 per cent too high. One can build very excellent factory buildings at the present moment in ferro-concrete for 8d. a cubic foot, and I fail to see why a laboratory building should cost three times as much.

**Mr. E. O. Sachs:** As an architect I appreciate the attention which the author has given to detail in the designs that accompany the paper. From the fire point of view there is only one aspect which I should like to see further developed in the plans presented, namely, that there should have been a greater division of the individual floors into sections or compartments. The corridors running from end to end on each floor without a break would, in case of an outbreak of fire, result in flame and smoke spreading very rapidly. Referring to the question of the construction of the class of building suggested, there is no doubt that reinforced concrete is the best form of construction to be applied to this purpose, from the point of view both of avoiding vibration and of obtaining fire resistance. It must not, however, be any form of reinforced concrete that is employed: it must be reinforced concrete that has been carefully designed to meet the special requirements of the case, and must comprise materials that are truly fire-resisting and not, as is so often the case, very much the reverse. The provision of ducts to carry wiring, pipes, etc., over the corridors is an absolute essential in good planning nowadays, but the ducts should be broken up in sections so that flame and smoke may not be carried along them in case of a fire. Open-work laboratory furniture is also welcome from the fire point of view. It is the cupboards with their dangerous contents of waste paper, odd chemicals, oily rags, etc., which are so frequently the cause of fire in institutions of the type under consideration. Turning to another point on the structural side, I think Sir Robert Hadfield's model of a building, with a basement, a ground floor, and a first floor is the best arrangement for a research labora-

tory. Personally I do not like too many floors in institutions of this class, and strongly favour a lay-out of large floor areas. I am also opposed to a flat roof and prefer the ordinary roof to work under. If a flat roof is essential, then it is advisable, in order to make the upper floor liveable and workable, to have at least a 2-ft. well-ventilated accessible air space between the roof proper and the ceiling of the laboratory; that is, to have what is generally known as a "double" flat roof. To turn now to the working of these laboratories, I greatly advocate team work. I have been over many research laboratories in different countries, and I have always found that the happiest and most successful laboratories were those where team work was developed. Club facilities should be provided in institutions of this kind in order to foster team work, and the library and the mess should really become the equivalent of the common-room of a popular college. Anything like secretive work amongst the men composing a research staff of a laboratory should be discouraged by the management. Every possible facility should be accorded for the interchange of views. As to the treatment of staffs by the management of works and laboratories, I have noticed in several research laboratories the unpleasant feature of the "clocking-in" and "clocking-out" system, which may be applicable to the workshop but is certainly out of place for professional men, whose best work as a rule is done just when "the spirit moves them." The freedom of the research staff is an essential for its successful work.

**Mr. H. Rottenburg:** I should like to refer to a point mentioned on page 155, where the author says "Information of this character . . . by a small trained staff." Some six years ago Professor Miles Walker suggested to me that we should prepare a paper to present to the Institution on the co-ordination of research, but on making inquiries he found that apparently nobody wanted such a paper. I feel that the reason against the adoption of co-ordination was the individualistic feeling that if we once have co-ordination or control it will kill individualism. I cannot help feeling that the history of the world, especially in political development, has shown that the greatest individualism comes out when we aim at the greatest co-operation. One of the things Professor Walker and I discussed was the question of a centralized bureau where all indexing and recording of technical literature and of research work would take place, and I hope the result of all this discussion on research work will lead to something of the sort. One hundred incomplete indexes of technical information are not as valuable as one complete index. Such a centralized bureau should contain not merely a reference index of what had been published, but if possible some sort of record of the subjects on which different works had undertaken research without publishing results. Such a record would enable works to buy from others the results of research when such is not patentable, or to obtain the services of an expert on a particular problem. Another thing which might be done in such a centralized bureau would be to keep a record of all special apparatus that has been made by colleges, institutions, works, etc., for special research. This would enable works, etc., to hire from others apparatus which at present is wasted after the special work it was designed for is finished. There is one little point in connection with the duties of a director which the author has not mentioned, namely, the question of enthusing the men under him. For the last four years the glamour of the war has enthused us, and look what it has produced —unstinted voluntary work. How can we get that enthusiasm in industrialism? One method which has succeeded well in America apparently is the introduction of the competitive spirit between works. In this country it is resented by many unions. We might begin, however, by informing employees about the different achievements of the research staff, the selling staff, etc. Finally, there is the investigation of ideas submitted by outsiders, which I think must be taken up in a more scientific way, and it must be one of the functions of a research department. Our attitude in the past has been badly influenced by the fact that it was always considered safer to condemn than to recommend new ideas. To have advocated and supported an invention which later proved to be a failure was counted too much against a man.

**Dr. W. Rosenhain:** I find myself very much in agreement with a great deal of what the author has said, and I will therefore not dwell upon that, except with regard to the reference he makes to the necessity of experimental plant forming part of the equipment of a research organization. I think that is a very vital part of the matter, because in many cases the difficulty lies in using the results of research. That big step between the laboratory and the works cannot be bridged without interfering with production in the manufacturing establishment. The author, rightly I think, points out that experiment and production must be kept apart, but I think he is not quite consistent in that respect in other parts of the paper because, for instance, he suggests that it is advisable to carry out routine and research in the same establishment under the same organization. Routine testing is essentially part of production, and if, as Dr. Hedley said, the research worker is going to send his experimental alloys into the routine laboratory to be analysed and tested, the routine workers will very soon complain, for it will interfere with the number of routine analyses they can complete in a day. In occasional cases where that has been attempted, the result is that individuals have been set apart to deal with this special work for the research section so as not to interfere with the routine work and the routine laboratory. There is further a fatal objection to the whole scheme, and it is one I would strongly urge upon the consideration of those who have to deal with the matter, namely, that the research laboratory should not be at the works. It might not, I think, be even near the works. The reason is not that I wish to see any divorce between the work of the research laboratory and that of the works: there should be, and must be, a common purpose underlying the whole; but the atmosphere of the works is the atmosphere of production, and the atmosphere of the research laboratory should be the atmosphere of research and experiment, and the two things do not harmonize. The effect of the works

atmosphere will always be to drive the research laboratory into directions dictated by immediate necessity and urgency, and will tend to hamper that following of the big things which in my opinion should be the right function of the research organization. Turning to the question of the design of the buildings, I am afraid I find myself, as the result of a considerable amount of practical experience, rather opposed to the author's views. I would suggest that neither the author nor any other man, least of all an architect, can lay down how a research laboratory ought to be designed. I would urge most strongly that the right people to design a research laboratory are the men who are going to work in it. In other words I would say, first establish the organization, that is, get together the director and the heads of departments and let them co-operate with a competent architect to produce the proper designs for the particular laboratory which is to be set up. I have seen the reverse effect, particularly in certain of the large German laboratories, where very elaborate and beautiful buildings, some of them with a very strong family resemblance to the pictures we have seen on the screen, were erected, but when the research staff were put into them they found themselves in quite uncongenial surroundings. The rooms were not well designed; they were not well adapted to the purpose; the architect had had too much to say; and if the men who worked in the laboratories had been consulted in the designs very much better results would have been achieved. I also want to draw attention to another point which has already been mentioned by other speakers, namely, the author's suggestion that research can be reduced to a business. I disagree cordially and fundamentally with that idea. To aim merely at research directed to a well-defined objective is to stultify the whole idea of research. The research worker must be left free to follow where his work leads him, and unless he is allowed to do so he will miss the best and most important results of his work. It is for those who want to use the research to follow the research worker and utilize his work rather than to constrain him into directions which he ought not to follow. I think very likely I am misinterpreting the author's meaning—probably he is very much more in accord with me than would appear from his remarks—but that is the attitude I take up. That covers, for instance, such a question as the hours of the workers, their discipline, their vacations, and matters of that kind. Finally I would say that perhaps the most important thing of all in a research institution is the point that Mr. Rottenburg has already referred to, viz. leadership from the director of the laboratory and leadership from the head of each department in it. To say that research work can be done by men of ordinary intelligence without such leadership is thoroughly to misunderstand the nature and work of research institutions.

**Dr. W. H. Hatfield**: The paper deals with the subject in a satisfactory manner, particularly as regards the lay-out of the laboratories. I have the pleasure of directing the research laboratories of one of the large armament interests, and it may be of interest if I describe briefly their activities. I have placed on the table the plans of our research buildings, so that those members who desire to do so can see the arrangements which we have found actually successful over a number of years. I refer to the Brown-Firth Research Laboratories which are financed by Messrs. John Brown & Co. and Messrs. Thos. Firth & Sons. We adopted, in the first place, a very wise attitude which has proved to be right as time went along, viz. to dissociate the research work entirely from routine testing. Sir Robert Hadfield has mentioned Krupp's laboratories. In 1914 I visited Messrs. Krupp's laboratory, and Sir Robert will no doubt confirm that the routine testing is there carried on in the same block of buildings as the research work. The result is an imposing edifice but actual disadvantages to those men engaged on the research side. Our own works say to me: "If the works people worry you with minor difficulties which the managers should be able to solve for themselves, i.e. problems which are not really of a scientific nature, you should refuse to do the work." I am in general agreement with the author on many points, and am therefore taking one or two points at the outset with which I do not agree. The second paragraph on page 156, under the heading "Staff," is liable to misconstruction. One rather gains the impression that a staff composed of what the author calls "ordinary type men" would be satisfactory for research work. One understands that these "ordinary" men are to be resourceful, energetic, and well-trained. To my mind these three traits or characteristics are not commonplace, and I raise the matter because the personnel of a research laboratory is the beginning and the end of things so far as success in its ultimate work is concerned. I notice the word "energetic" is used, and it is well perhaps to point out that some of the men with the most intellectual, highly-trained minds may hardly be considered energetic. For that matter, energetic, in a conventional sense, is rather contrary to that attitude of mind which is necessary for the contemplation of scientific data, and I suggest that rather than bodily energy, what is really needed are minds which have the characteristic of activity and originality. Such men are, of course, in an entirely different category from men who are passing a year or two in the laboratory with a view to ultimately taking control of works operations, in which latter case the usual traits necessary for business efficiency must be placed first. I noticed on page 156, under the paragraph headed "Administrative," that the author proposes to charge the cost of each investigation to the department for which it is done. That is all very well in its way, but is very difficult in practice. I do not think that the research laboratory should be worried with cost cards, etc., for each individual investigation. Apart from a general desire to carry through the investigations without extravagance, I do not think that much can be done. The accounts department in the works can readily allot, with sufficient accuracy, the charges incurred by investigations done for the different departments. With regard to the functions of the research organization and the author's comments on pure science and industrial research, I agree that it is necessary to draw some distinction between pure

science and industrial research, but however necessary it may be, I am afraid that it will be a little difficult to draw a clear distinction. In my own mind I recognized that scientific work must be placed under the two headings, viz. pure science and applied science. Even such a distinction must, however, be somewhat arbitrary, as it is extremely difficult at times to dissociate the one class of scientific work from the other. Definitions are always very difficult, but I will attempt to define the two somewhat as follows:—

*Pure Science.*—Work leading to an extension in our knowledge.

*Applied Science.*—The application of such knowledge with the object of increasing the efficiency of human life in any direction whatsoever.

The cost of the introduction of newly discovered laws and facts to human use is in itself sufficient indication of the fact that the applied scientist has further to extend human knowledge in devious minor directions before the major law or fact becomes a human convenience. Hence, to a minor degree the applied scientist is inevitably in part a pure scientist. The pure science worker is a philosophical individual with a high order of intellect, frequently one who is inclined to neglect, or even scorn, the mercenary side of things, and who is sufficiently occupied and interested, and at times gratified with the progress of his investigations. Unfortunately there are such types of mind which are little troubled even about their own convenience and, at times, quite oblivious to the convenience of society at large. In other words, they are investigating the laws of nature largely for the love of the work, and it is necessary that the application of science shall be left to the more practical minds of the applied science men. The latter individuals should have an expert knowledge of the particular fields of industrial activity into which it is desired to bring the influence of the new knowledge. They should have a considerable amount of tact and no inconsiderable knowledge of human nature. In my mind the applied-science man cannot be too intimately associated with the business which it is intended he shall benefit, whilst, on the other hand, he must be thoroughly in touch with the progress of pure science. I will take this opportunity of observing that, since human nature is essentially conservative, it is necessary that on the works side there should be a sufficient number of men of scientific training and of sufficiently receptive and progressive spirit to facilitate well-considered modifications of process and changes of method which may be suggested by a research organization. Incidentally, I would remark that if the industrial processes of this country were even in line with present knowledge they would, in most cases, present a vastly different aspect from the prevailing one. For the successful development of the present movement for giving industry the fullest advantages of scientific work I feel that the following conditions must be satisfied:—

(*a*) A much more adequate support and encouragement for pure science entirely dissociated from the economic or industrial side.

(*b*) The selection and training of a much greater number of applied-science men.

(*c*) The introduction of many more, highly trained men actually into each industry, and under this heading we might include the necessity for the higher training of those men already there.

(*d*) The development and support of scientific societies for the propagation and discussion of both pure and applied science of interest to specific industries.

With regard to (*a*), I have often thought that panels should be formed for each industry of the leading applied-science men with a view to determining the fields of pure science likely to be of most immediate advantage to the industry, and that those branches of investigation should then be supported by adequate financial aid. More chairs might be created in convenient universities and institutions, with the creation of considerably more research fellowships. If each industry and profession contributes, in a proper degree, to the support of pure science, it will be obvious that throughout the country pure science, as a whole, will not lack the necessary means for prosecuting its important work. With reference to (*b*), such men must be drawn from the universities and institutions, as mentioned in the foregoing. They should also be drawn from the industry where special genius is apparent, and a great deal can be done in this direction. With regard to (*c*), I consider this to be absolutely fundamental. There is a considerable dearth of this type of man throughout the whole of the British industries. The professions and the Civil Service attract far too many men, and it therefore seems to me to be absolutely necessary for industry to show that it can offer equal possibilities of advancement to those men who have the necessary natural gifts and intellectual attainments. Personally I am afraid that we shall not find a sufficient number of such men without drawing our net through the whole of the strata of society. When we come to (*d*), I feel that if the previous items were adequately dealt with, this last item would take care of itself. The "Proceedings" of the different societies are invaluable means of facilitating the application of science in the different industries and cannot receive too much support and encouragement. With reference to the use made of scientific work, everything depends upon the enterprise of the particular companies concerned. A company which is enterprising will make much out of a single new fact, whereas in companies lacking enterprise, profit cannot be taken from a host of facts. In discussing this matter one feels tempted to discuss the question of the use of public money in scientific work. There is, throughout the country, quite a feeling in some directions that Government money is likely to be turned to private profit, but I consider this to be a very narrow view. The Government now shows signs of supporting scientific work to a much greater extent than in the past, and if, when researches are published, some private profit is made by certain companies in applying the results to their manufactures, surely the employees in particular, and the community in general, obtain considerable benefit, not only in the remuneration received in the first place, but by the object of applied science being

obtained in the second place, viz. the successful application of such knowledge with the result that it has increased the efficiency of human life in some particular direction.

**Mr. J. G. Pearce:** Mr. Paterson has asked how it is possible for the man selected for research work to be kept on that work without having to perform the routine tests incidental to his work or to concern himself with petty details of administration. The combination of routine testing and research offers great opportunities of economy in this direction, for the chief of the routine testing section can be made responsible for order and discipline in his section, without the research man's direct responsibility being affected in any way. Various speakers view with alarm this arrangement by which a routine-testing section performs tests required during investigations, some because they consider it desirable that the research man should be entirely responsible for all the details of his work, while others, although recognizing the necessity for relieving the research man of work which can be done by those of more limited training, consider that separate provision should be made. The precise view taken will in general depend upon experience and upon the particular circumstances of each case. In a steel works, since the variety of routine tests is small, and since the number required can be calculated beforehand, the routine testing goes forward with the precision of clockwork, and it is clearly disturbing to have a research man requesting tests which are non-standard. In an electrical works, however, with which the paper is mainly concerned, the variety of routine tests is large and their incidence irregular, and extra tests can readily be accommodated. In fact, they form a recognized portion of the total load. The separation of routine testing from research in an industrial organization is, in the early stages of development, attended by grave disadvantages, as many difficulties providing subjects for investigation in materials and processes are revealed only by and through routine tests. The combination of routine testing and research in one organization does not imply that the research man will be expected to perform routine tests. The reverse is the case, the routine testing section being expected to relieve the research man. Much work of an investigational character consists in the expert evaluation of and comparison between results of routine tests. Further, a laboratory may not undertake specific research in pure science and yet may carry out its work in industrial research in a truly scientific spirit. Industrial research ceases to be research if it becomes empirical in analysing and correcting causes. The subdivision of the laboratory into sections does not imply lack of flexibility. The sectionalization merely permits continuity to be maintained. The library should not be the passive instrument usually found associated with laboratories, but should include an information service in connection with which all relevant matter from external sources such as books, pamphlets, and periodicals, and from internal sources such as records of work done in the research department itself, should be abstracted, indexed, filed, catalogued, and distributed. This information should be treated as it appears for subjects known to be of interest and special searches instituted for new information as required. Industrial research laboratories will, in future, form an essential part of the country's research facilities, and will develop special relationships with laboratories of research associations on the one hand, and with national and university laboratories on the other. Industrial amalgamation will enable the larger groups to establish and maintain research laboratories of the largest type illustrated, with routine testing laboratories at the individual works. Working on such a scale is advantageous owing to the greater specialization permitted and to the close contact of a large number of research workers. Similarly, a group of smaller non-competitive firms may be enabled to establish a co-operative laboratory.

**Mr. A. R. Everest:** As the author remarks, the question of organization is very important, and I am disappointed that he did not deal with it more in detail, because it seems that in the proposal given on page 154, covering the functions of such a works research organization, there is room for a great deal of difference of opinion as to whether some of the items properly fall within the scope of the research organization. Many of those functions are generally carried out by other departments of the works, and if we are going to broaden the scope of our research laboratory and draw into it quite a number of other functions previously handled by other departments, we shall get into difficulty. One case that I have in my mind is point No. (9) on page 154, "Investigations of operating troubles and service for customers." The investigating engineer has not usually been on the staff of the research organization; he has been on the commercial engineering staff, and to make the function with which he deals a branch of the research laboratory would involve some dislocation. Other points could be discussed if time permitted. I should also like to ask the author's opinion as to the position which should be occupied in the research organization by the specialist researcher. It is not clear how he would fit into the author's organization—whether he is to be given a little room to himself to work in. Will that be the case, and will he be able to call on the general staff for assistance when he wants it, or will he simply be a worker under the general head of the department?

**Professor C. R. Darling:** I should like to make a few remarks on the co-operation of small employers. It is my experience that there are a great many employers who are quite willing to devote a certain sum to research, but who could not afford the large amount that is mentioned in the paper. An organization which could afford the annual expenditure suggested, even for the smallest laboratory, would have to be on a fairly large scale; and it would help not only myself but others if the author could give an idea as to what percentage of the annual turnover of an organization ought to be devoted to research. I am aware that it must vary according to the nature of the work that is done; but taking a broad view of the question I should like to know what the author suggests. It might be possible for a number of smaller firms working on similar lines to co-operate and insti-

tute a research laboratory which would serve their combined needs. With regard to the staff for research laboratories, the question arises: where are we to get the men from? It is suggested in the paper that a number of them might come from the lower grades of the staff who might be found to be competent and worthy of promotion to a higher position; but apart from that the only suggestion which is made by the author is that they should come from the university. I think that rather narrows the ground from which these men should be drawn. I might point out that that qualification would have excluded Faraday. Also the word "university" occurs so frequently in the paper that although perhaps the author means it in a wider sense it is a little apt to do injustice to the Imperial College of Science and Technology, which is not a university and which at the same time might provide very good recruits for research laboratories. If I might suggest an amendment to the paper I would add, after the word "university," "or good technical college," because some of the best research men have been drawn from the technical colleges. The chief trouble in organizing research laboratories in this country will be, I think, to find the right men. If we can only get a director who, in addition to all the other manifold qualifications mentioned in the paper, is expert at discovering good men, then he will be worth any salary that we like to give him.

**Mr. H. Davies:** I am asked to say on behalf of the Department of Scientific and Industrial Research that the paper has been read with much interest and is regarded as a notable contribution towards the organization of industrial research in this country.

**Mr. A. Collins:** Industrial research may be classified under two broad headings. Under the first heading occurs certain classes of research which should be carried out on co-operative lines. This may include work which is of general interest to a group of firms, or it may be that the investigations have to be carried out on such a large scale that they would be prohibited by reason of their expense if left to the enterprise of an individual firm. Under the second heading there is a large amount of work which each firm must carry out for itself. Some of this arises in connection with the development and design of the particular apparatus in which the firm may specialize, and satisfactory solutions of such problems may be more readily obtained, I think, by the firm's own research engineers who are familiar with the apparatus and the circumstances of its use. We have in this country instances of organizations on similar lines to those illustrated in the author's slides, but it is to the credit of British manufacturers that many of them have carried out valuable industrial research in the past, using nothing more than their ordinary routine testing equipment. We have ample evidence of this in the numerous developments for which this country has been responsible, particularly so far as the equipment of some of the super-power stations now being erected is concerned.

**Mr. E. H. Rayner:** There will be no doubt as to the value of the paper, especially among those who have to control commercial policy and who are uncertain whether the founding of a research department would be commercially sound and, if so, what the cost is likely to be. In many instances I am strongly of opinion that in the case of firms of any reputation it is not a question whether they can afford to, but whether they can afford not to consider research as an essential to their continued healthy existence. My position during the last few years has brought me into contact with firms of different sizes manufacturing all kinds of articles. There is the old-established firm whose name has been renowned for a century. There is the considerably newer firm in the same line, which has perhaps equalled the elder and is getting ahead. There is the firm of medium age which was semi-bankrupt and was kept going practically as a national factory by the Ministry of Munitions. What is the reason of these vicissitudes of commercial concerns? Not, I think, up to the present time, necessarily due to the want of research and experiment, though this is doubtless an important item, but rather to an ignorance of their own ignorance. This ignorance appears to be often in the elementary chemistry or physics of their processes or instruments. The firm which is ignorant of its own ignorance will have no chance in the future. Those who do realize that they do not know everything, and still more if they are aware they only know a little, are in a fair way to salvation. They naturally try to get information from other sources and do perhaps do a little experimenting themselves, and so keep their heads above water. To return to the paper, I find that on page 154 the author makes suggestions as to when research in pure science can be justified, and comes to the conclusion that probably only large firms can afford it. I think it is true that the deeper one goes to the root of physical conditions the more likely one is to strike gold and get at the cause of trouble; and, after all, technical research is very largely digging for the cause of trouble. I would be chary of advice as to limiting technical research in this manner, without a warning as to possible disappointment. In the interesting series of paragraphs on page 154, col. 2, I looked to see how many were the special functions of a national laboratory, and was glad to find only four, viz. (2), (7), (8), and (12). It was quite a relief not to be saddled with two-thirds of them. On page 155 I should like to emphasize the importance of a liberal workshop equipment, already mentioned by Mr. Paterson. Every new investigation requires new plant of some kind, involving construction in a workshop. An undersized shop is a most fruitful source of waste of time of the research staff, when a wait of two or three days has to take place instead of one, which might have been necessary with better facilities. The intelligence department of a laboratory of this nature is most important. The literature on every branch of applied science is so vast, and the various branches interlace in such a multitude of patterns, that some sound and time-saving method is required to feed the various sections with information, just as a naval and military intelligence service exists for the Admiralty and the War Office. I hope others will make concrete suggestions on this most important point. I like the quality demanded of the workers in a research laboratory, "that they should be capable of distinguishing

cause from effect." If we could do this effectively there would not be much need for research laboratories and we should, for instance, be on terms of familiarity with the internal economy of an atom. However, I most strongly endorse this importance of a full measure of the sense of physical logic, the cultivation of which is one of the aims of a liberal education. As to buildings, I would point out, as a matter of small detail, that I would not put a battery room as shown on the ground plan of Fig. 13, viz. alongside the main entrance. The space is too valuable and the fumes will get into the main corridor. The ideal plan is to put it well away, and I should suggest it being put on the top floor when possible. It may require a specially strong floor, but, if this can be provided, the further away it is the better. At Teddington we have gone as far as to have no internal door to the battery room. There is a special outside staircase to the second floor, and the scheme has been entirely satisfactory. As to lighting of buildings, if large rooms are required a top light is very desirable; but, for delicate manipulation and fine instrument work, I believe instrument makers will agree with side lighting. Top lighting for such purposes is like using indirect lighting when sewing. The ladies do not like it, as there are no shadows, and for fine work contrast is essential. I fully endorse the points set out in the conclusions on page 169. A position unassailable at the present moment has been obtained by certain firms by spending money on research, and their products are not of the cheapest. When it is realized that the best is nearly always the cheapest, no tariff will protect the inferior article. Only public ignorance can do that. In regard to the last few paragraphs of the paper, I hope that in the future there will be thorough intercourse between the public and the various commercial research laboratories. Certainly the public laboratories cannot keep themselves up to the mark without it; and I hope it will become a recognized practice. The idea of visiting research students seems to be a most excellent one for giving advanced students an insight into the aims and methods of the workaday world. The firms giving such facilities will not be the last to benefit by it.

**Dr. A. H. Railing:** The subject of the lecture has been constantly before the manufacturers of this country during the last 10 years, but until the last few years very little headway has been made; the aspect, however, has changed to a great extent on account of the educational campaign carried on by men like the author, Sir Robert Hadfield, and a few others. The leaders of big industrial concerns in years gone by were not over-keen in putting down capital for the purpose of industrial research, chiefly on account of the fact that accountancy classified such capital outlay and expenses under the heading of unproductive labour. Times have changed, and to-day manufacturing concerns, or anyhow large manufacturing concerns, realize to the fullest possible extent the necessity for such research. The author has classified the various classes of laboratories which are necessitated by varying conditions of different industries. Where, like in the steel industry, research is confined to the production of one commodity, or at any rate commodities of similar character, although research might be complicated, the institution of a research establishment for such work, however, is comparatively simple. On the other hand, for large electrical manufacturing concerns, producing a large variety of commodities ranging from a turbo-generator to cables, lamps, telephones, etc., the establishment of a research establishment laboratory, or of research laboratories, becomes a very complex question. The author has given very valuable information in regard to the organization of laboratories, but there is one point on which a good many of us would be very grateful to have some further information, and that is, how research laboratories of the second class, which he mentions on page 154, organize the different functions of the central control laboratories as against the laboratories of the individual works. The problem before a number of large electrical manufacturing concerns in this country is that we want, for a number of our works, laboratories which on the one hand must be in the closest possible touch with the works concerned, and on the other hand under the central control of a central research laboratory. I feel that the time is past when capital has to be educated up to the value of research, and I feel the measure of success which could be achieved in our laboratories will, to a great extent, depend upon the way in which the managers of the various works can be brought to collaborate with research institutions, either attached to those works or centrally situated, and vice versa. It would be interesting to get some further information from the author, if he can give it to us, for instance, as to how far centralization or decentralization of research has been found useful, say, in the large American concerns. In regard to general topics, I have only one further remark to make, namely, that I particularly welcome the author's remark on page 157 that the research laboratory should be in the closest possible contact with the educational authorities which are now being set up in our various works. It is from such institutions that we must draw the help for improving the education of the technical staff and for giving the inspiration and the broader outlook which is so necessary to counteract the monotony that results from the ever-increasing routine work, due to increased specialization. I should like to refer to a few details in the author's proposals. I should like to refer first to the last paragraph on page 155 in which the author dwells on the necessity of having as detailed and complete reports as possible on all investigations carried out in a research laboratory. I should like to add that there always seems to me in such reports a need to dwell not only on positive results which have been achieved, but to give what I may be allowed to call a "negative" report, that is to say, to indicate clearly other avenues which, given time and opportunity, should have been investigated, but which, for the time being, had to be left alone in order to achieve a positive result in the shortest possible time. Such indications very often yield very excellent results when at a later date it is possible to pursue their study further. I entirely endorse what the author advocates in the second column on page 150 where he points

out that a research laboratory should be run with the best possible man on top and comparatively young men and women for the ordinary work. It is to be hoped that men of the latter calibre will be available in time to fill positions in the works and to bring their knowledge into the production departments. Coming to the laying down of buildings, I should like to ask the author to explain further his remarks at the bottom of page 161 where he states that the construction of a concrete frame and brick fabric lends itself to more effective lateral lighting. I cannot quite see the reasons for this preference, as it seems to me that equally effective lateral lighting could be effected in a concrete building. I would further ask whether the standard of illumination which he mentions in the second column of page 164, viz. 3–6 foot-candles, is not somewhat on the low side. Even in manufacturing establishments we have arrived already at a higher figure for illumination, and reports issued lately in the United States seem to indicate that the standards used there are higher as well. The last item on which I have any remarks to offer is the cost of buildings. It is rather important that manufacturers who intend to put down laboratories should not be deterred, and it seems to me that the author's figures for concrete buildings are somewhat on the high side in comparison with figures which I recently had before me.

**Mr. E. B. Wedmore:** I shall confine my remarks to a few broad issues which arise out of the paper and the remarks of previous speakers. We have been considering an excellent programme for the development and organization of research, but this programme will require a number of trained men for putting it into execution. Prior to the war there was already a shortage of "reliable, energetic, well-trained" technical men, and during the war there has been a constant diminution of the influx of such men. On the other side there has been a large increase in the amount of electrical plant brought into use in this country, and with the further large increases which we contemplate in the next decade there will be a very great demand for trained men in all branches of the industry. From this it is evident that men engaged in the manufacturing section will be urgently required to meet the daily technical needs of production, and there will be difficulty even in finding men for developing new designs urgently required. I therefore doubt very much if there will be any material progress made in research in this country unless every possible use is made of co-operative effort to economize in the employment of technical men. There are many problems in the electrical industry which everyone knows have to be solved. Some of these are problems which can be dealt with by routine methods, and the interested parties working independently will arrive at substantially the same solution. This sort of work puts a strain on the resources of each individual manufacturer, which could be greatly minimized by co-operative effort. It is true that there is a large class of problems in which advantage may accrue to the individual manufacturer if he finds a new solution in advance of his competitors, but the race will always be to the swift, and the increase in co-operative effort will not remove the scope which remains in invention and design for the best man and the best-equipped concern to get to the front. Technical data are the very life-blood of the designer. Technical data are a kind of property different from most other kinds, in that we can divide it amongst any number of individuals without any diminution of the original quantity. It resembles the miraculous loaves and fishes, and we know what would be thought of a man who, possessing this kind of bread, were to attempt to keep it to himself. In my view we should aim at a condition in which every designer should have access to all the existing data. Existing methods of circulating technical data are altogether inadequate. One may take, for example, pocket-books on technical formulæ and constants. Data on the magnetic properties of iron are amongst the most fundamental in our industry, yet the typical pocket-book gives magnetization curves based on Hopkinson's work, now half a century old, and I doubt if it would be possible to find the corresponding quality of iron in the market at the present day. We have two good technical libraries in London, one of which has a good catalogue. Both these libraries close at 5 o'clock. The publication of *Science Abstracts* has made a good beginning in bringing the results of research within reach of the individual worker, but does not meet the need as it should be met. A great deal of time is involved in hunting through the numerous volumes to find the data required, and the volumes serve primarily as an index to articles which have been written. It too often happens, but perhaps through no fault of the abstractor, that numerical results are given without any reference to the units used, and with little or no indication of the degree of accuracy. Students from our technical colleges are not sufficiently trained in the use of significant figures and in the ways of determining the accuracy of experimental results. There is no reason why this sort of training should be confined even to technical men. It ought to form part of the training in mathematics in secondary schools. One has seen tables giving dimensions of Whitworth nuts in which the dimensions across the corners are given to four decimal places, and this sort of error would be more frequent were it not that the accuracy of a slide-rule corresponds roughly to the average accuracy of good experimental work. Now the development of any system of co-operative effort for the production of technical data will lead to the introduction of a central organization. This organization should serve many useful purposes. It should act as a clearing house, for example. This would facilitate the free flow of technical data in just the same way as the bankers' clearing house facilitates credit and the free flow of money. Subscribers should be able to obtain data and references to publications by return of post, and even on occasion by telephone. Any man or body of men standing in the way of the free flow of technical data is doing a disservice to the community. There is, however, a class of research which involves a considerable capital expenditure, and which would not be carried out unless there were some guarantee of a reasonable likelihood of a profitable return on the money expended. I am not sure that the patent laws do not alone furnish ample guarantee. They are

specially intended for this purpose, and aim at ensuring that there shall be publication and free use after a reasonable period. Every designer is familiar with the fact that there are many problems which can only be solved by research, but which he cannot tackle, as the cost is too great to provide an adequate return. Where, however, there is co-operation for research, each party contributes only a small proportion of the cost and the research then becomes a profitable one. Another useful function which a central body can perform is that of inducing scientific workers to undertake researches of industrial importance. It may be wrong to recommend scientific workers to make researches for money, but, following a well-known precedent, there is no harm in recommending them to make researches where money is. I think all engineers who read the "Physical" section of *Science Abstracts* will agree that there is a body of able research workers who might be drawn on to assist in research of immediate value to the industry, and ultimately this should react to the benefit of research work in pure science. Even a small country like Switzerland has had an organization publishing important papers, for example, on switches and fuses, the result of organized co-operation. Large organizations such as that of the General Electric Company of America, through their research section, publish an immense amount of technical data of great value to the whole community. We have not yet caught up with the work of the Verband Deutscher Elektrotechniker, although we are now in a fair way to do so. To attain the maximum benefit of co-operation it will be necessary to co-ordinate the efforts of all the engineering and scientific bodies. This is to my mind work of national importance of the greatest urgency, and I hope the Institution will be able to make a move in this direction.

**Mr. C. T. S. Arnett** (*communicated*): I am greatly interested in items 3, 4, 5, 7, and 8, on page 154, and I think that these items can be applied to the engineering department of large electrically-equipped iron and steel works. In the first part of section II on page 154, the author does not include a department to investigate the cause of electrical breakdowns, their prevention, or the advisability of installing new machinery balancing the cost, interest, and depreciation against the saving of man-hours and the profits due to increased output. There is a great need for such investigations in large iron and steel works. Hitherto, in many such works, electrical engineering has been considered by the mechanical engineer and general manager as a necessary evil which need not be thoroughly understood so long as breakdowns on small motors were repaired quickly; and seldom is an electrical-mechanical engineer employed who could investigate and fix the cause of reduced output with certainty and with an unbiased mind, since he would belong to neither the mechanical nor the electrical department. Many works have large electrically-driven mills; these mills present many knotty problems in themselves, and investigations should be made on them which would be useful when more electrical mills are to be installed. None of these investigations can be made by the heads of the electrical or mechanical maintenance staff to the full extent that they should, since this staff has to devote all its energy to the proper organization of quick repairs and replacements, erection of extensions, etc., and cannot keep up to date with the theoretical side of steel-works engineering. The staff of such a department would be small and could consist of a chief investigating engineer, mechanical and electrical assistants, one draughtsman, one clerk, and two office boys. Men or apprentices could be drawn from the repair department when any extensive tests were to be made, and the above three engineers would also hold afternoon or night classes for apprentices. A representative of this department would visit other works, and receive visits from other works at the discretion of the general manager or chief engineer. This department would obtain information for the general manager or chief engineer to guide him in his future policy as far as engineering was concerned. The chief of such a department should be a man with a thorough electrical and mechanical training, both practical and theoretical, and have had experience in iron and steel works.

**Professor F. Bacon** (*communicated*): I am glad to see it stated in the paper that "the most important feature of a research organization is that of the staff" and that "the research staff should be considered to offer the most highly prized positions," but is it fair to state without contradiction or explanation that "it has been repeatedly emphasized that there has been a lack of technically-trained young men who are able to apply the results of scientific research in industry"? The directors and managers of industrial concerns should take to heart the saying that "it is the bad workman who complains of his tools," and be honest enough to admit that in the past they have done little or nothing to allow—far less seek out and encourage—likely young men to apply the results of scientific research to industry. A typical example of the British pre-war attitude is that of a large and well-known firm of engineers and shipbuilders, paying wages of £6–£12 to scores of their workmen, who employed a so-called research chemist at the munificent salary of £150 per annum and expected him to provide his own microscope. This is not an isolated case, and I am sure many members could match it with equally flagrant examples of apathy and neglect. Naturally the author has adopted a more enlightened standpoint; but, reviewing the paper as a whole, I doubt whether even he has taken a sufficiently wide and generous view of the treatment of the human element necessary to render a research organization really worth while. Those who have struggled and achieved some measure of success with both scientific and industrial research would generally admit that industrial research is of the two the more exacting on the individual, and by far the more difficult to provide with the organization and facilities requisite for success. In view of the fact that this country is now at long last about to plunge into industrial research without suitable traditions and in the face of actively hostile prejudices, I should like to protest against the views of the author where he speaks of industrial research as capable of being "reduced to the character of a business" carried on side by side with routine testing

by a staff, conforming as regards working hours and discipline to the practice of the works with which it is associated, under a director who is careful to avoid "aimless research having no utilitarian objective." I do not deny that even under such adverse conditions small improvements and economies may be obtained which in the aggregate would prove valuable; but nothing worthy of the dignified title of "research" can be expected to flourish in such a forbidding atmosphere. If a large firm decides to go in for and make a success of its own research institution, it should go about it in a sufficiently broad-minded way to attract and retain the *born* research worker, not so much by offering high salaries to the juniors, as by willingly according them privileges and opportunities for realizing their own genius unirritated by the trammels which inevitably surround production and routine. No doubt it is wise to keep exact account of all expenditure, and clerks should be attached to the research department who will do this work without distracting the research worker himself with such mundane matters as pounds, shillings, and pence. The director of the research department should be responsible only to the board of directors; and when the board decide to back a research of any magnitude, they must be prepared to wait 10 years, if necessary, before expecting to realize a return on their outlay. I think that the spirit of research will be deadened and hampered by mixing it up with the monotonous drudgery of routine testing. This danger can be averted without sacrificing the advantages claimed by the author for combining the two, by the simple and desirable expedient of putting the director of research in charge of all routine testing as well as the separately housed department of research. It is not to be inferred that I regard the research worker as too superior a mortal to soil his hands with routine testing. On the contrary, he would be all the better for a not too long apprenticeship at such work. What I do mean is that when a research worker is deeply engrossed in original work, it is false economy to call him off to attend to a routine test which by suitable organization could be equally well executed by a smart and reliable apprentice. In order to educate research workers up to the pitch of being in sympathetic touch with the actualities, requirements, and limitations of commercial life, it should be arranged that they must frequently come into close personal touch with all the higher officials of the firm, not forgetting representatives of labour. A representative of the research department should be required to attend all conferences of the works officials, even when the agenda does not include any item which visibly appears to demand his presence. An additional function of the research organization not included in the author's list should be the sifting of suggestions received from the staff and workmen and the development of any promising idea in sympathetic collaboration with its originator. The aim should be to stimulate and turn to good account the latent inventiveness of any employee who can bring forward a sound and promising proposition. To this end, it should be possible to allow any sane and serious worker in the employ of the firm to have the satisfaction and stimulus of exploiting his own "brain wave," supported by the research organization on a system which would avoid involving him in financial loss, and with the prospect of a fitting reward should it prove to be of value to his firm. It is a little unfortunate that the author's plea for a broad-minded policy in favour of publication, and against the vice of secrecy, is almost immediately preceded by the significant remark that research is "ultimately the only effective method of securing monopoly." The only way out of this dilemma would appear to be a wise and fair system of taking out patents. I wish that the author could have seen his way to make recommendations as to how to deal with this very important and difficult question of taking out patents in a way that would secure just and adequate protection for all parties concerned.

**Mr. A. T. Bartlett** (*communicated*): After reading the paper, and listening to the discussion, it appears to me that owing to the use of the word "research" a number of the speakers did not view the subject in the correct perspective and in the light intended by the author. The whole question should be considered in a broad manner. There are four essentials that an up-to-date works should possess, namely, (1) facilities for routine testing; (2) facilities for the improvement and development of its standard and similar products; (3) facilities for research work proper, which may be the solving of a particular problem on pure research with less definite motive; (4) an information bureau and library. Now, of these four, the first two are absolutely essential. The third and fourth are not so essential, but are most desirable, and further, given a good staff and facilities for the first two, it is possible and probable that a considerable amount of what may be termed "applied research" will be carried out. A separate research department is probably only justified in the case of a large and wealthy concern, and I think it would help one to get a better-balanced view of the matter if one termed such an institution, say, a "testing and experimental laboratory," a title which is broad enough to cover everything. From this it will be clear that I consider in the average works a testing and experimental laboratory should be set up under one chief, who will have under him, according to the amount of work to be done, assistants more or less specially allotted to a specific class of work. The functions of this chief should be to control all tests (even if a separate routine testing laboratory is justified), development, research, and information bureau. The development of standard products may possibly, at least in the early stages, be carried out with advantage by a works expert under the ægis of the chief, but I would most strongly urge that all facilities for experimental work should be centred in one spot, and not scattered, as one speaker proposed, in a number of departmental development shops. One can never foresee in work of this kind what apparatus and facilities will be required in any particular department, and it will inevitably happen, unless testing plant is kept together, that work will be delayed, or actually prevented, not because the necessary plant has not been purchased, but because

it is not available owing to its being too far away. The above speaker also stated that the same apparatus would not be required for the development of generating plant as for the development of an electricity meter. This is not correct, but the duplication—except of standards for checking sub-standards—is not serious; however, in the case of the development of, say, generating plant and heavy switchgear, it is clear that both will require similar expensive power plant and converting plant, which should not be duplicated. In the case of those concerns having works in different towns, a research department should be set up in one of them to deal with the more subtle problems and pure research. Each works should have its own testing and experimental department for its own urgent and specialized needs; and the staffs of these departments should be in frequent conference, and frequent interchange of visits should take place in order that all may become acquainted with each other's views and difficulties and thus render each other valuable help, and incidentally, but most important, become the connecting link between the technical and manufacturing staffs of the different works and the research laboratory. In fact, such a conference might, with the director of the research laboratory presiding, well form a committee of management of the whole of the research development and experimental work undertaken.

**Mr. A. G. Collis** (*communicated*): I do not think the author's proposals are likely to meet with enthusiastic reception, since the suggestions have not the proper conception of the wants of the profession, except under special circumstances. The proposals are too costly and would prove unremunerative. From page 169 the total capital outlay appears to be anything up to £71,400 approximately, with an equivalent annual cost of anything up to £75,000 per annum. This naturally does not cover the whole cost of such an experiment, but taking the figures as correct, and assuming a company with a total output of £500,000 per annum, the additional expenditure for such work would impose from 25 to 30 per cent increase in the selling price of the manufactured article. It might be suggested that the reduction in works cost by the research laboratory would cheapen its production. Statistics, however, are available on this, from which it is gathered that the reduction of works cost by such means is very small compared with the introduction of increased business. I do not think there are many managers of works who would like to approach their boards with such a proposal as that outlined in the paper, unless supported by arguments that would prove the commercial success of the enterprise. If such an amount of money were available, I am disposed to think they would use it for other purposes. What in my opinion is required is the erection of such laboratories for the use of a number of firms; these laboratories to be State-aided, with a subscription for their support from each firm interested. Possibly in some districts it might be of advantage to use the present dormant machinery in colleges, which not only serves as an education to the students but might be of value in conducting the experiments required by manufacturers. The success of all such proposals depends on the encouragement of the enthusiastic worker. At present there appears to be no recognized reward for talent, and certainly before the building is erected these and many other points upon which depends the success of any such innovation require settlement. Research work necessary for the reduction of works cost is now adequately conducted with the plant and material available in all up-to-date firms without this expenditure. Research work for the perfection of new designs and ideas can be provided for in the manner suggested. Academic investigations would be a fruitful source to those students who intend to follow the course, as suggested above, by a professional career. I notice with regret that the paper is associated on page 157 with a recommendation to employ university-trained men. I think the author should immediately rectify any misconception as regards the exclusion of others who have not been so fortunate; and in this connection he will need no reminder that a large number of the men who have contributed to the welfare of the industry made no claims to the distinction drawn in the paper. As a matter of fact, most of them were not educated in the manner suggested. One of the benefactors responsible for the present method of producing steel was a clerk getting £80 a year, who had not had the training referred to. America appears to have a large number of these research laboratories. This country has at its disposal very efficient means for acquiring the same result which has placed this nation foremost in the realms of science and industry. The greatest contributions to science and industry have emanated from British brains. I dwell rather on this so that no false impressions should be obtained from the paper.

**Dr. W. H. Eccles** (*communicated*): The paper is very happily timed and should prove of assistance both to the firms who have decided to embark upon research and to those who have only begun to discuss the matter. To the latter especially it should prove helpful by contributing fairly definite data to their deliberations. The author in writing the paper appears to have assumed the obviousness of the need for industrial research in this country, but I should like to point out explicitly that the war has rendered industrial research much more urgent than even before the war. The outstanding fact in this connection seems to me to be that the United States has become a more formidable industrial rival than ever Germany threatened to be. In the first place, America has come through the war without any wastage whatever of her technical and scientific personnel, and thus retains intact what Mr. Campbell Swinton has recently pointed out in an Address to the Royal Society of Arts is an invaluable part of the industrial capital of a nation. This country, on the other hand, has lost in the war many men of great experience, skill, and knowledge. In the second place, America has been enormously enriched by payments for the services she rendered to the Allies before entering the war, and we have been correspondingly impoverished. Doubtless this westward shift of mobile capital will draw with it much of the inventive talent which formerly brought to this country from the European mainland such vivifying forces as are repre-

sented by the names of Siemens, Ferranti, Marconi, and so forth. Thirdly, according to some people, the fact that America is "going dry" will enhance the mental activity of the brain workers of that continent. Even before the war it was noticeable that the increasing complexity of modern civilization was not fully realized in political, commercial, or industrial Britain. As a nation, we cling to rudimentary ways of doing things. Doubtless it is due to this trait in our national character that we never adopt a new thing until it is made obvious and easy, and that our manufacturers were prouder to hold the heavy chemical trade than they would have been to produce instead the brainy and beautiful synthetic chemicals such as drugs and photographic compounds—though these were more lucrative. We appear to excel in building great dams and railways, where the ratio of manual labour to mental is large, much more than in, say, the building of optical instruments, where the mental labour is the more important. Perhaps this is because the profit in the former case is more immediate and more obvious to the business man, and not because we are less gifted mentally or less adaptable to the increasing complexities of civilization. The author, in drawing up the paper, appears to have been swayed by these considerations and to have felt especially the need of convincing the business men controlling our electrical industries that there is a chance of making an industrial research laboratory immediately useful. Some of our business men seem to be rather unimaginative, and even the far-seeing ones have in normal times to meet shareholders annually and present a balance sheet. To such men, the author's list of the functions of a works research organization may appeal convincingly; for the list includes a great deal of obviously useful testing of materials, a number of plainly promising investigations, and at first sight very little abstruse research. Indeed, for real research, in the sense in which the word is used by men of science and inventors, the author makes little provision throughout the paper. Now it has always seemed to me that advanced research is the truly profitable and beneficial thing, and as "research" occurs in the title of the paper, I take this opportunity of emphasizing this view. True scientific research may be undertaken with the motive of advancement of knowledge or with the motive of extending or founding an industry. The motive, it seems to me, is the only difference between abstract research and industrial research. In both branches the passion for learning to read a little further in nature's infinite book of secrecy must animate the votaries. In both branches the workers make discoveries and inventions; but in abstract research the inventions are usually directed to improvement of the apparatus and methods of making discoveries and obtaining data, and to the linking of facts by theories; while in industrial research the inventions are directed to the introduction of newly discovered facts and principles into manufacture. But in both kinds of research the workers must have the passion for learning, must possess creativeness and inventiveness, and must be observers and reasoners born and trained. Moreover, both kinds of research add to the common stock of knowledge and, ultimately, become useful. Of the two kinds of research, it seems to me that industrial research is more exacting and more difficult than abstract research, if only for the reason that besides all the qualities of the abstract researcher it demands ideally a practical spirit and a deep and accurate knowledge of a technology and its history. In addition, the industrial researcher is brought to an early judgment of a much more searching and retributive kind than ever falls upon the abstract researcher. It follows, therefore, that I do not believe that research can be reduced to the character of a business or be organized on systematic lines. But I know investigation may be so organized; and investigation may lead to many improvements in detail in manufacture and may, in short, help a factory like a sound system of book-keeping does. Investigation, as the word is usually understood, is different from research in that originality and creativeness are not essential parts of it. For instance, an investigation of a firm's accounts is perhaps better done by unimaginative persons than by inventive ones, provided they are properly trained in the well-known principles of accountancy and business and have had experience. The author is quite right, it seems to me, if he means that a great deal of investigation (as distinct from research) can be carried on by the co-operative efforts of ordinary men; but it is always to be remembered that ordinary men rarely see the tiny sparkle of the gems uncovered by their investigations. How many ordinary men between the times of Cavendish and Rayleigh investigated the composition of common air without perceiving the presence of argon? Thousands! And now argon is an important commercial commodity. The author, having placed all the routine testing work in the research laboratory, is constrained in his scheme of administration to place upon the research director the control of, and responsibility for, both the routine work and the research work. Doubtless under such an arrangement the head of the research department would be able to appear before his board of directors as a person doing obviously useful testing and checking; but if the head of the department is a man of much creative ability, no greater waste of time and opportunity can be devised than to load him with routine administrative work. Surely the ideal research director should be free to enter deeply into the researches of all his subordinates, should be up-to-date in relevant discoveries everywhere, and should be alert to see and seize opportunities unfolded by the published work of other minds in other laboratories. For instance, if a new way of obtaining electrons is discovered in the Cavendish Laboratory, then the research director of a firm interested in any kind of electrical discharge should be able to project his mind over the whole field of possible applications and to arrange for the setting up and repetition of the experiment if this course were decided upon. This means he must have leisure for reading, thinking, discussing, and inventing, and that nothing so entangling as routine should have any call upon his attention. All the same it is most necessary that the organization of the works laboratories should be such that the research department

should have at least as strong a claim as any other department on the services of the testing laboratories, so that he may be able to overcome the dislike these often display to doing what they regard as "fancy" testing. I may mention here that during the past three or four years I have had the privilege of taking part continuously as consultant, technical committee member, visitor or actual director in researches carried out by the three fighting services, both at home and abroad, and am assured by this experience that it is best to keep testing apart from research so as to avoid the humdrum attitude of mind; and this whether the aim is to find new solutions or to effect improvements in known methods. Indeed this all follows from the fact that the object of research is to do something never done before—which is the very antithesis of routine. Finally, I would point out that no amount of investigation on commonplace lines can introduce into an industry any fundamental advance, such as, for example the work of Coolidge brought into the X-ray industry; and, worse still, the experience acquired in commonplace investigation is not sufficient to enable its possessors to make even a passable copy of the products of their more advanced competitors.

**Mr. P. M. Fraser** (*communicated*): I cordially agree with the author's preference for one-story over multi-story buildings. Human and mechanical energy are lavishly wasted in multi-story buildings, and all problems of interconnection, heating, lighting, labour-saving installations, etc., become more expensive and less efficiently solved. On page 163 the author recommends flat roofs, but these are attended with the vital objection of condensation, which in certain processes is absolutely inadmissible. The whole of the plans indicated show, to my mind, too great a subdivision, and I cannot but believe that several of the departments could be amalgamated in one compartment with considerable gain in efficiency. More than one speaker alluded to the apparently high figures given under the heading of "Capital Outlay." They are certainly at least 40 per cent above pre-war costs. Referring to the installation of sprinklers, it would be wiser if these were regarded from the single point of view of reducing insurance premiums. From the factory owner's point of view they cause often more damage than a fire; but as a fire is an abnormality and the insurance premiums are routine certainties, it is obviously a wise policy to protect the buildings, having in view that it is possible to secure over 60 per cent rebate thereby. On page 166 the author states, referring to Fig. 25, that a double row of columns is necessary. As such columns may often be objectionable, I should like to point out that columns are not at all necessary to carry such a duct, especially in a reinforced concrete structure where it can be suspended from any part of the ceiling efficiently and economically.

**Mr. A. Johnson** (*communicated*): Research organizations can generally be classified under three headings: (1) national or co-operative, (2) industrial, attached to any one works group, (3) experimental, attached to a particular works. Research in pure science would naturally be relegated to the first division. The function of such an organization would be to establish facts. Such facts or phenomena would then be introduced to the industrial laboratory (2), where research would be carried a stage further in order to determine whether and how these scientific facts could be applied to any particular industry. The abstract idea would be developed, not necessarily on commercial lines, and a concrete form produced. Obviously such a product is not of the slightest use for immediately introducing to the factory for quantity production. It would then be forwarded to the experimental laboratory (3), whose sole aim should be the production of an article suitable for manufacture commercially. All climatic, rough usage, functioning and durability tests should be fully carried out in this laboratory. To illustrate the above remarks, the introduction of Bakelite as an insulating medium may be cited. The fact that this commodity can be produced by the action of by-products of the coal-tar industry in the presence of a catalyser would constitute the work of the laboratory in the first division. This crude material would then be treated by division (2) to determine the physical properties and to produce it as an insulating medium. It would then receive attention in the third division with a view to obtaining the best method of utilizing it commercially. The author of the paper advocates that routine testing should constitute the basis of the work of a research laboratory. Any works, however, contemplating the installation of a research department will naturally have a properly organized inspection directorate. It is therefore considered that the work which is already being carried out by the inspection department, viz. mechanical tests of material, chemical analyses, etc., should continue to be dealt with by that division and most certainly not be transferred to the research department. The latter should be quite untrammelled by routine work of this nature, since it would ultimately preclude the possibility of research being undertaken, due to the rapid growth of routine work in proportion to the expansion of the activities of the factory. When the inspection department finds faults occurring which affect the correct functioning of the article, the research division would then be requested to investigate the possibilities of improving the material. It is submitted that a department undertaking routine work of the nature advocated by the author is not a research but an inspection department. In the table on page 154 setting forth the functions of a research department, item (11) would appear to be foreign to research and would devolve on the employment bureau in a works of any magnitude. If the research department comes under the financial control of a company running a factory or factories, it would be preferable and economical for the costs to be administered by the accountant's division of the works, in order not to cramp the activities of the director of research with such comparatively petty details. The selection of the staff and the administration of the laboratory demand very careful consideration by the management of the company. The director must of necessity be a man possessing organizing ability and of wide experience. He need not possess the highest qualifications in every subject, but it would be desirable that his strong points should lie in the

direction of the work for which the laboratory was established. He should be an enthusiast capable of securing harmonious team work, inspiring his deputies, and indicating generally the lines on which research is to be conducted initially. He should be adequately supported by deputies at the head of each subdivision, i.e. metallurgy, chemistry, physics, etc., who should possess the highest qualifications for the posts occupied. The design of the building, if not already erected, should be determined after the director and his deputies have been consulted, a competent architect being called in then to execute designs in accordance with the requirements. It has been suggested that the sprinkler system of fire protection has serious disadvantages which are likely to produce as much damage as would be caused by fire. It is suggested that a gas under pressure might be substituted for the water, thus enabling the existing pipe lines and sprinklers (made leak proof) to be utilized. The gas could be treated in a manner such that, in the event of a sprinkler head fusing, its presence would at once declare itself (say by its pungent odour) and enable action to be immediately taken by the staff to reduce the liability to anæsthesia to a minimum.

**Professor E. W. Marchant** (*communicated*): The need of industrial research in modern industry now requires no emphasis; it is recognized on all sides. There is, however, one subject mentioned by the author which has received far too little attention, i.e. investigations of a physiological and psychological nature. Although these subjects have not received any definite place in a scheme of research organization, the underlying principles have been practised in all manufacturing, and indeed in all professional undertakings, since industry first started. Success in any large undertaking depends far more on the choice of personnel than on any other single factor, and the instinctive exercise of those powers which enable the man in charge to choose the proper person to carry out any part of the work in hand, is the secret of successful management. Whether it will be possible to apply strictly scientific methods to a process which has been, and still is, a fine art, remains to be proved. The result which may be achieved in assuring that in no organization round pegs are in square holes, is so great that the attempt is well worth making. As far as the choice of men to carry out particular processes is concerned, there is undoubtedly a great field for psychological investigations, and of this no one has had greater practical experience than the author. There is little to discuss in that part of the paper which deals with the design of the laboratory. For those who have ample and well-lit areas on which such laboratories can be built, there is nothing to criticize. In most cases within my experience the space has been limited and it has been a problem to fit the necessary laboratories into the space that is available, a task which, of course, in each individual case must be dealt with on its merits. I should like, however, to say something on the question of the salaries of research workers. I have dealt with this subject on many previous occasions, and I am convinced that it is of fundamental importance, because it controls to a very large extent the type of person that will ultimately be available for research work. Unless really adequate salaries are offered for research posts it will be almost impossible to maintain a high standard of efficiency in a research laboratory. A really first-class man will not take up engineering research if the ultimate prospect is a salary not much higher than that paid to a foreman joiner. The research laboratory should become the heart of any great manufacturing concern, and unless that fundamental organism is retained in a state of full and abounding activity the organism is bound to weaken. The author has mentioned the part which it is hoped the universities and technical colleges may take in any scheme of industrial research. That part will, I hope, be of increasing value and importance to industry; but although the universities will themselves produce an increasing output of original investigation, their chief function will always be the training of research workers. It is for the manufacturers to see that the best intellects are attracted into that branch of their organization which will, I feel certain, ultimately lead to the greatest development in their output and in the quality of their products.

**Mr. P. G. Pettifor** (*communicated*): If research work is to reach its greatest incentive and effectiveness in this country, and more especially as applied to the apparatus and accessories side of the electrical industry, it will be necessary for the manufacturer to become more specialized and to handle the parts in such large quantities as to give the most effective inducement to thorough research. This has undoubtedly been the main cause of the great development of research in America and Germany, and has also been proved by the large amount of research work carried on in this country in connection with munition supply and fostered to a large extent by the large quantities handled of the one type. There must also be a close bond of interest between the electrical manufacturer and the supplier of raw material. Some time ago in making some researches into magnet steel I found the steel manufacturer very loath to produce samples of various tungsten contents steel. The same experience was also had in other directions. It would seem therefore that central industrial laboratories as described on page 154, section (2), are in such cases likely to be most effective.

**Mr. C. F. Proctor** (*communicated*): I think one of the most important problems in connection with the success of works research laboratories has only been very lightly referred to, namely, the importance of getting improved methods discovered by the research laboratories adopted by the works. Employers often blame—and not without reason—the workers and the trade unions for opposing new methods and labour-saving appliances, and yet are often very loath to acknowledge, and slow to adopt, improvements suggested by their employees. The success of a works depends not only on the early adoption of the great epoch-making discoveries which the research laboratories may give us, along with the minor and often well-defined troubles which they may succeed in eliminating, but also on the innumerable little appliances and dodges worked out by keen workers, and I am afraid that unless the works can be made to see the necessity of

taking up promptly every improvement that will pay for the cost of its adoption, we shall not get the full advantage of the money spent on scientific research, neither can we hope to keep up to our foreign competitors, who generally hail every improvement with enthusiasm. The problem is very much one of making both the employer and the employee realize that we as a nation are not sufficiently awake to the fact that the foreigner is steadily reducing the lead which we had in almost all of the great industries. I feel that a nation must either rise or fall, and unless we keep our methods not only up to date but also well ahead, we cannot hope to maintain our lead. How nearly our want of foresight in the great struggle scarcely yet terminated brought us to the latter state many of us scarcely yet realize, and until labour and capital appreciate that they are as necessary to each other as the male is to the female, we shall not get the close co-operation of labour and capital that is necessary for complete success. Do our labourers realize that capital, and even knowledge, are only stored-up labour, and that labour is useless without knowledge, or in other words capital, and that capital is equally useless without labour? The work which those in our laboratories are setting out to do is to collect together all the stored-up knowledge—or work—on the subjects of most interest to us, and see how it can be applied in a way which will diminish the labour at present necessary to procure a certain desirable object; or by supplementing the present state of knowledge by new discoveries, obtain for us some new device; or by addition to our general fund of knowledge, and so prepare the way for future improvement, i.e. to minimize labour or increase capital, and so add to the general welfare of the people.

**Mr. G. H. Roberts** (*communicated*): On page 153, col. 1, par. 2, the author states that only a fraction of the research conducted in universities and technical colleges in the past has been directed to industrial requirements. I think he really intended to say "immediately directed" or "purposely directed," because all research work is ultimately of benefit to industry. It is regrettable that under (3) in the same column the author is apparently not in a position to refer to any similar institution in this country. Again, under (6) the author touches upon a subject which must occupy a much more prominent position in the future than it has in the past. The amount of waste which goes on in manufacturing concerns in this country at the present time is simply appalling, although in many cases proper care and attention to such leakages might turn a financially unsuccessful firm into a successful one. Matters are doubtless very much better now than they were before the war in the matter of utilization of scrap and waste, but we have still a lot of leeway to make up. In paragraph 10 in the same column, by "financiers" the author probably means "the financial staff of the firm concerned." In the "Optical" section on page 155 the author refers to the application of colour testing to routine work. I am not clear what is meant by this, and I shall be glad if the author will explain or amplify his remarks a little further. Under the heading of "Illuminating" in the same column, I suggest that the author might add "investigations on the lighting of factories from the standpoint of intensity, uniformity, efficiency, and cost." Under "Pyrometric" also the author might have referred to the practice, now becoming fairly common in large works, of installing centralized pyrometric control of all thermal operations, such as heat treatment of steel forgings, thus ensuring uniformity of treatment and regularity of results. Again, under "Materials" I suggest that the duties of any such department, whether as sellers or purchasers, should include responsibility for seeing that standard specifications such as those of the British Engineering Standards Association are introduced and worked to on every possible occasion. From the remarks under the heading "Intelligence and information section" in the second column of page 156, the author is apparently of the opinion that the necessary information may be satisfactorily collected by persons other than those engaged on the actual research and who will require the particular information. With this general statement I entirely disagree. I feel very strongly that it is only the person who is engaged on the actual research who can say exactly what it is he wants to know, and the particular point on which he requires information. I agree that a preliminary search might be made by an able and intelligent staff in such a way as to save a good deal of the principal's own time, but my point is that this preliminary search must stop at the point of merely indicating where similar and pertinent information can be found, leaving it to the person carrying on the research to appraise the value of this information actually and if necessary digest and use it. I quite agree with the author's remarks later in the same paragraph as to the importance of keeping adequate records and the use of a standard plan in preparing reports. Under the heading of "Administration" in the first column of page 156, the author touches upon one of the delicate points which has to be considered in connection with the conduct of all research laboratories, viz. cost. Speaking from my own experience, I consider that the setting aside of a definite sum for each particular investigation is very liable to cramp initiative, and tends unduly to limit the object of the research unless some arrangement exists for increasing the sum available as required to bring the investigation to a satisfactory conclusion. As this appears likely and possible, I should like to suggest an alternative method as regards works laboratories, viz. that a certain lump sum should be placed at the disposal of the responsible head of the manufacturing department each year to cover the cost of all minor investigations or researches carried out for his department, the only conditions being that the researches should be in connection with the work or production of his department, that the cost should be accurately debited to the particular research, and that the result should be reported in the customary way. There should, however, be no responsibility attached to the head of the department or those in charge of the particular research in the way of explaining or excusing liability if successful results did not follow. In other words, a recognition of the fact that a negative result is frequently as valuable as a positive one,

although in the former case there is frequently a tendency, especially on the part of a purely business man, to look for the reason of the apparent waste of money. In the last paragraph of the first column in page 156, the author states that the staff should conform in the matter of working hours and discipline to the practice of the works with which it is associated. While this may be laid down as a general rough standard, I do not think that the directing staff of any research laboratory should be tied hard and fast as to definite hours; the work is of such a nature that there must be a considerable amount of give and take. At the bottom of the second column on the same page the author enunciates some very desirable qualifications respecting the staff to be employed on research work. It is very unfortunate that the present system of training does not seem well adapted for the production in sufficiently large numbers of the highly qualified staff required for undertaking research in actual works: on the contrary, there appears to be a decided tendency, so far as the so-called theoretical side of the training is concerned, to turn out men who prefer the comparative calm of the university or technical school laboratory rather than that of the works. It is comparatively seldom that one finds a man who has done good work in the one leaving it to go to the other, although considerable experience in both is very necessary from the standpoint of broad training and a wide outlook. I am of opinion that more could be done in the direction of permitting apprentices and pupils in engineering works to spend some portion of their time of training in the laboratory, particularly the mechanical laboratory, as it may very well be that this would be the means of discovering a considerable amount of latent talent. In making this suggestion I am quite aware of the fact that in some works this is already the practice, and many instances could be adduced of men who subsequently attained distinction who first found their true *métier* by the opportunities so provided. On page 157, par. 2, the author refers to the Mellon Institute of Industrial Research, Pittsburgh. If he could give in an appendix a brief account of the organization of this place, he would add materially to the interest of the paper. On pages 158 to 162 inclusive, the author gives several typical lay-outs of buildings for research, and of these I am of opinion that the one shown in Figs. 7 and 8 is by far the most suitable, except that I would prefer the future extensions to maintain unbroken lines along the existing wings. This design has the following advantage:—(1) It could be started on quite a small scale as regards accommodation by merely having a single frontage with or without end wings. (2) The wings can be extended almost indefinitely without any interference with the lighting of each other, or of the front block, or the internal courtyard. (3) If so desired, one of the wings could be devoted solely to machinery and the other to light delicate apparatus. (4) The courtyard could be covered over and used for all manner of useful purposes. (5) By having the two wings parallel to each other on two sides of the courtyard the convenience of access is maintained in spite of almost unlimited capacity for growth. There are also in my opinion many other advantages on which I need not dilate. On page 163 under the heading "Elimination of vibration" the author mentions the choice of fabric and method of construction. In this connection I would point out the extreme desirability, when designing a structure, of providing suitable points of support for plant and apparatus of all kinds which may be required subsequently. Another point to be remembered is the undesirability—if the building is to be used for accurate electrical or magnetic work—of making the skeleton of the building of magnetic material such as steel. If this be not altogether possible, at any rate no moving or movable parts should be of magnetizable material. On the same page, in connection with "Lighting," I would suggest the desirability of having all machinery and apparatus painted white. This practice has been followed in America in some engineering works, although I have some reason to believe it is not found wholly successful there by reason of want of attention and other difficulties, such as that of the smoky and dirty atmosphere in some places. In the laboratory, however, it should be possible, once having got the machines painted white, to keep them absolutely clean and in the same condition, and this, by reflection, must add materially to the general lighting of the interior of any such building. I would also lay stress on the provision of the utmost amount of natural light, either by roof glazing or by windows, and recommend that wherever possible such glazing should amount to at least 50 per cent of the external wall areas. On page 166, col. 2, the author tabulates the different kinds of supplies for which a building must be piped. To this I would add the suggestion—which I have found very useful to a limited degree in somewhat similar circumstances—that each one of these should be painted with a separate identification colour. On page 157 the author refers to ventilation of laboratories, fume chambers, hoods, etc. In several laboratories fitted up during the last few years for the ventilation of which I have been responsible, "Ejector" systems have been installed and have proved most satisfactory in service. They are perhaps slightly wasteful in power, but are extremely reliable and effect great saving in maintenance and upkeep on parts such as spindles, bearings, motor winding of fans, etc., when dealing with acid fumes. As regards the heating of the rooms themselves, I am of opinion that a pressure system—combined with a heating system if necessary—is on the whole the most suitable; it is under better control that an extraction system, and so far as necessary lends itself more readily to washing of the incoming air with a view to extraction of dust, grit, or soot. On page 169, col. 2, last paragraph, the author touches upon one of the delicate points in connection with research work, viz. the extent or otherwise to which the results of research should be made known. In a paper which I contributed to the Summer Meeting of the Institution of Mechanical Engineers at Cambridge in 1913, this point was dealt with, and a suggestion made that there should be established a kind of "clearing house" for dealing with the results of such researches as could, and properly should, be made public. The same point was also commented upon in remarks by various speakers, as it was generally anticipated that

this would form one of the stumbling-blocks of any considerable scheme of industrial research, but, as the author correctly states, this attitude has been weakened to a considerable extent during war-time. On page 170 the author suggests that the great industrial organizations having well-established research facilities will extend their hospitality freely to those workers in universities and elsewhere to conduct important investigations. I consider this to be a good idea, although it would probably mean that such work would have to be undertaken during the university vacation.

**Mr. E. G. W. Souster** (*communicated*): With reference to the remarks made by Dr. Garrard upon the cost of the buildings illustrated in the paper, the costs given were obtained by preparing approximate quantities, which were then priced at pre-war London rates. It is not reasonable to compare the costs of factories with those of research buildings, as the finish of the latter must of necessity be of more expensive materials than would be used for the former. As regards the figure of 14s. 9d. per superficial foot, a reference to Table 5 shows that the most expensive building is only 13s. 4d. per superficial foot of floor area, and if the cubic contents of this building are taken to the outside of the external walls and from the top of the foundation concrete to the top of the roof (the accepted surveyor's method) it will be found that the cost is roughly 10d. per cubic foot.

**Mr. A. P. M. Fleming** (*in reply*): The discussion has been so full, and different aspects of the same question have been touched upon by so many speakers, that it has been convenient to arrange my reply so that the points raised have been dealt with under several main headings.

*Routine testing and research.*—The feature in the paper which has undoubtedly attracted most attention has been the suggestion that the routine testing and research work should be combined in the research organization, some speakers giving it cordial support, others equally cordial condemnation. The arrangement advocated in the paper is suggested as appropriate in the initial stages of development, and the advantages accruing for a works organization are overwhelming. In the case of a national or other laboratory the same conditions do not apply, and consequently a rigid separation may be desirable. In very few works would the directors be prepared to create an entirely new department for carrying on research work which would have to link up with other works departments. Further, a department so created, especially if staffed by men brought in from outside, would never develop the intimate relationship desirable between the research and manufacturing departments. The obvious solution of the difficulty is to associate the existing testing and experimental work, including routine testing, and allow the new department to grow into a research department. As pointed out by Dr. Hedley, this arrangement is economical, because when a research man requires routine testing to be done he can place it in the hands of those much more expert than himself while he proceeds with his work. It is not suggested that the research man should be employed to do routine tests. The routine testing sections are adequately staffed and equipped for the work they have to do, and the research man has no responsibilities beyond the investigations for which he is engaged. Such an arrangement will solve the difficulty suggested by Mr. Paterson, of highly paid research men being preoccupied with petty details of administration. As mentioned by Mr. Pearce, the chief of each routine-testing section can be charged with the responsibility for cleanliness, discipline, supplies, apparatus, and laboratory routine in his section, including, if desirable, those rooms in which specialist researchers are working. In this way the latter may be relieved of all responsibility except for research alone, and may get any assistance required from the routine laboratory.

It should be noted that in electrical works there is a wide range of routine tests, few of which can be so closely standardized as is possible in iron and steel works. Non-standard routine tests from specialist researchers do not therefore give rise to complaint, and in any case one would think that such tests would bring a little welcome variety. The line of demarcation between investigations and tests is not clear, and any division necessitated by the separation of routine and research work will be largely arbitrary. There are many minor investigations arising in works practice which can be done by routine workers.

Sir Robert Hadfield is undoubtedly right in suggesting that this country is not so backward as is commonly supposed, and much of the varied investigation carried out by industrial firms has been done, often without encouragement and under difficult conditions, in the ordinary routine-testing laboratories. This is a further reason why such laboratories should form the nucleus of a research organization.

Many of those who advocate the separation of routine testing and research, on the ground that the presence of the former is inimical to the latter, such as Dr. Rosenhain, Dr. Hatfield, and Dr. Garrard, do not sufficiently appreciate the educational function of a research organization in an industrial works. This point is amplified in the paragraph below on "Staff."

The research department should welcome works men who bring problems arising in works practice, for no matter which involves scientific and technical knowledge and which aids manufacturing efficiency should be outside its purview. It should be closely knitted with the rest of the works organization, and the close interlinking is best obtained by uniting the research and routine-testing sides, the latter being part of the production system. A department separately organized for research alone does not have the right atmosphere. It tends to become self-conscious and apart, and physical separation from the works assists this tendency. It is vitally important that research should come to the aid of industry without reservations, and even making sacrifices to prove its value. Otherwise many manufacturers will remain unconvinced.

With reference to the point raised by Mr. Everest, the research department would not usurp the functions of those engineers engaged on development or on solving operating troubles. It would, however, in consultation with the engineers concerned, carry out any experi-

mental work required for development, and continuous co-operation between the engineering, commercial, and research staffs permits experimental work to be concentrated and adequately performed. With reference to operating troubles, it is generally conceded that, in the past, complaints from customers have seldom had the attention they deserve in this country. Few troubles arising on apparatus in service can be treated without reference to the research department, but any work so carried out would be done in co-operation with the engineers interested. The department would not supplant or overlap their functions, but would provide expert opinion and testing facilities when required.

*Buildings.*—With regard to buildings, I am gratified to find Mr. Sachs in general accord with the arrangements suggested. The question raised by Mr. Paterson of single-story buildings of large size deserves lengthier consideration than can be given in a reply. The choice between single- and multi-story buildings rests entirely on the amount of land available, and the illustrations in the paper assume, as is generally the case in industrial areas, that land is scarce. The multi-story building offers advantages in easier supervision, greater accessibility, both interdepartmentally and with respect to the works, and higher publicity value. The cost, however, would not be sensibly different, and if the cost of land is included, the single-story arrangement would be more expensive. This type, however, offers better possibilities of extension, greater flexibility, larger active working space factor for the same gross floor area, and better lighting, and some internal structural features, such as ducts and ventilation arrangements, are simplified. The saw-tooth roof is undoubtedly a very advantageous form, except for chemical laboratories, unless the steelwork is encased. In order to get fullest lighting and freedom of certain parts from vibration, separate unit buildings, say, 120 ft. long by 50 ft. wide with a double saw-tooth roof span are desirable. Such a unit would be a brick building with piers and roof principals pitched 10 ft. apart, and a 7 ft. by 8 ft. window between each pair of piers. A height of 14 ft. to the eaves is suitable. The trough in the roof could be supported by steel girders 30 ft. apart.

The Institution is indebted to Sir Robert Hadfield for the opportunity to inspect the plans of Krupp's laboratories and the model of his new research building.

I would point out to Dr. Rosenhain that the paper does not aim at providing ready-made schemes, but at enabling those manufacturers interested in research work, who have not hitherto had occasion to consider it as a practical proposition, to see what is involved with regard to staff, buildings, and equipment, and at indicating the relationship with the works which experience suggests is desirable.

In reply to Dr. Railing, the statement regarding lighting at the bottom of page 161 is a comparison between a brick fabric and a reinforced frame with brick fabric for single-story buildings. The case of a concrete fabric is still better, but is not used for single-story buildings, and consequently does not enter. When the economy of good conditions for highly paid research workers is more generally realized, laboratories will doubtless be erected on sites not rendered unsuitable by the close proximity of manufacturing buildings, as Professor Marchant has found to be often the case.

*Character and organization of research work.*—I am fully in accord with the need for creating a true research spirit in industrial laboratories, emphasized by Mr. Barnes, but it must not be thought that, as apparently suggested by Mr. Barnes and Mr. Rayner, because a works research organization makes no specific provision for pure science research, its industrial research is done in an empirical and therefore unscientific manner. There is only one research method, used in both pure and applied research, and each type requires men of high scientific training. The distinction between the two is merely one of objective. The ideals actuating the two men are the same, as pointed out by Dr. Eccles, and I am particularly gratified that both Dr. Eccles and Professor Bacon consider industrial research the more exacting and difficult type, an expression of opinion which I have hitherto hesitated to put forward.

With reference to the query raised by Dr. Railing, I would suggest that a central research department organized for a group of works should carry out all researches common to the group, and all researches peculiar to one works not requiring actual works equipment, so as to secure the advantages of concentration of staff and equipment. The output of a laboratory increases much more rapidly than its size, owing to the increased specialization permitted and to the influence of the specialists on each other. At each works there should be a control laboratory under a responsible head dealing with routine tests for the control of materials and processes, and these heads should be responsible to the research director at the central laboratory, reporting routine test results to the works manager. Conferences should take place at frequent intervals so that information on methods of testing may be exchanged, and materials and processes throughout the group may be standardized. The most successful and highly organized laboratories in America may be taken as examples of such concentration. Frequently, even in one concern, it is necessary to have routine laboratories away from the main works, as is instanced by the travelling laboratories of a transport system. Much research work required should undoubtedly be done on a co-operative basis, as pointed out by Mr. Collins, and such work, which may be illustrated by the experimental work required to establish the technical data referred to by Mr. Wedmore, may possibly be undertaken by co-operative research associations. Mr. Bartlett has correctly grouped the main divisions of work, and possibly many boards of directors would view favourably proposals for a testing and experimental laboratory when suggestions for research would rouse less enthusiasm. Specialization in manufacture undoubtedly assists the introduction of research, as pointed out by Mr. Pettifor, because the field is narrowed and cost is decreased. Specialization, however, especially in complex products, is generally the outcome of research work, and this,

if continued, is the necessary corrective of standardization, often found in highly specialized products.

The point raised by Mr. Proctor is of great importance. All branches of the manufacturing organization, design, selling, manufacture, and research, must advance together if the best result is to be achieved, and this can only be done when all departments are open to receive and to apply new ideas without prejudice or undue regard for traditional procedure. At the present time a great deal of work is being done by the user of materials and apparatus which should be done by the supplier. Suggestions for improvement come from the consumer, instead of the supplier closely studying and anticipating the consumer's requirements. In the case suggested by Mr. Arnett, doubtless co-operation between the section to which he refers and the manufacturer would yield good results.

In reply to Mr. Fraser, the subdivision in a laboratory depends on the volume of work done and its variety. I am unable to agree to the classification suggested by Mr. Johnson, as there is no reason why co-operative research in the first section should be wholly in pure science, nor is the distinction between (2) and (3) clearly marked.

*Staff and salaries.*—I need scarcely say that I am in cordial agreement with Professor Darling's views regarding the sources from which research men should be selected. They should be as wide as possible, and include not merely the universities, but university colleges and technical institutions, and, of course, suitable men should be drawn from wherever they may be found. Many men of an inventive type of mind, who may frequently be useful in a research organization, have grown up outside the conventional educational system. There is reason to believe that, with better organization of the engineering profession, greater inducements, improved educational facilities, and closer co-operation between the works and universities, the shortage of men feared by Mr. Wedmore will be relieved. The suggestion in the paper that the laboratory should be utilized as a training ground is not intended to apply to the staff of the laboratory, although there are occasionally excellent reasons, quite unconnected with the question of remuneration, for transferring a member of the staff to a manufacturing department. In the exercise of its educational function, the laboratory should take for short periods those public school and university men undergoing a course of apprenticeship for the engineering profession. In this way the industry becomes permeated with men having some degree of appreciation of the value of science in industry and of its methods of application, and although generally engaged in a junior capacity on routine tests, such apprentices have opportunities of meeting and being stimulated by research men. Apprentices of graduate standard, showing the necessary characteristics, may be selected for entry to the research department at the conclusion of these courses. The further point raised by Dr. Hedley in connection with salaries is of great importance. The salary of £200 per annum mentioned in the paper is merely a basis used for ascertaining costs, and it is a pre-war average, taken as including all workers in the laboratory down to the office-boy or janitor. The salary of a responsible head of a section of the department would be at least equivalent to that paid to a university professor or works manager. Each laboratory must settle this all-important question for itself. The encouragement of research men through bonuses is a difficult problem. I found that a number of different schemes had been tried in America, such as a bonus to the individual worker, or a bonus to the laboratory divided in various ways, but neither is very satisfactory, as such systems either tend to operate against co-operative working or offer little real inducement. I believe that the proper solution is to increase salaries as a return for high efficiency.

Dr. Hatfield is probably much more in agreement with the paper on the point of staff than his remarks would indicate. It is essential that manufacturers should bear in mind that the type of man, often a genius, who succeeds best at pure science research is not necessarily required for works research. Such men are rare. If employed, however, they should be allowed to develop as Professor Bacon suggests. As a consequence, the men mainly available are "ordinary" men who have the necessary training and personal qualities. Dr. Hatfield's assumption that the "ordinary" men are to be "resourceful, energetic, and well trained" is incorrect, as the text states that the men required should have these qualities, but would be "otherwise" ordinary. The director of a research organization would of course have considerable discretion in dealing with working hours and holidays, and rigid conformity can be relaxed when it militates against the aim which the laboratories have in view. It is extremely unwise for members of the research staff to be placed formally on a different basis from the rest of the works, as this at once creates an invidious distinction which it should be the aim of the director to avoid.

*Costs.*—The point in regard to the cost of buildings which has been raised by Dr. Garrard has been dealt with by Mr. Souster. In reply to Professor Darling, I may say that the Eastman Kodak Company spends about two-thirds of 1 per cent of its annual profits on research work, and the Pennsylvania Railroad Company finds the cost of testing materials about the same percentage of their value. Mr. Collis is in error in assuming that the largest building described would necessarily be established by a firm with an annual turnover so small as £500,000. The large industrial group which would be able to maintain such a building would have a turnover of many millions.

Dr. Hatfield suggests that research men should not be worried by having to account for expenditure. The costing should, of course, be organized so that no time is required on the part of research men, and it is scarcely necessary to point out that ascertaining costs does not mean limiting them. Business men who are broad-minded enough to provide funds for scientific research are prepared to find that some expenditure is abortive and that research men may make mistakes. It is very necessary that costs of investigations should be accurately known. Only when this is the case can the director be sure of not exceeding grants for upkeep, or prepare estimates for future expenditure.

*Miscellaneous.*—The reference to "monopoly" quoted by Professor Bacon concerns the securing of the bulk of the trade in a given article, and when secured in the teeth of competition there is no cause for complaint, as the public get higher quality for a lower price than can be obtained elsewhere. The broad definition of industrial research given in Dr. Eccles' illuminating contribution will be welcomed by those engaged in it. The reference to research having the character of a business is perhaps unfortunate. It refers to systematic covering of the field in a number of researches rather than to the method of carrying out an individual investigation, and represents the antithesis of the way in which a field of work is covered by pure science workers, each working on a basis of individual choice, which leaves the investigation of some portions more or less to chance.

The abstruse research desired by Dr. Eccles should be done, but develops as a natural growth out of the organization suggested.

The interesting points raised by Mr. Roberts may be accepted. The procedure of allocating a sum for a research is not bad if supplementary sums can be obtained on showing the need for these. The distribution of grants has in many cases to be left to the discretion of the director.

For an account of the Mellon Institute of Industrial Research at Pittsburgh, I may refer Mr. Roberts to my pamphlet on "Industrial Research in the United States," published by the Stationery Office.

The last paragraph of Dr. Rosenhain's contribution is doubtless correct, but no supposition of the character suggested is made in the paper. Mr. Rayner's suggestion that some firms are ignorant of their ignorance is quite justified, and only a progressive policy will ensure a successful future. Mr. Rottenburg's suggestions are of considerable interest, and doubtless the question of a combined technical index will receive early attention. Professor Bacon's suggestion that the research department should investigate workmen's suggestions is decidedly good, but experience has shown that in a highly technical industry little progress is obtained through this. Indeed, research is necessary because progress is no longer possible by empirical methods. It is very desirable that workers should feel that their suggestions are taken seriously, impartially investigated, and the weaknesses shown to them.

# CARBON BRUSHES: CONSIDERED IN RELATION TO THE DESIGN AND OPERATION OF ELECTRICAL MACHINERY.

By P. HUNTER-BROWN, Associate Member.

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The expression "carbon brush" is here used in a generic sense and is intended to include brushes made of carbon and/or graphite, with or without the addition of various metals.

The characteristic properties of carbon render it a peculiarly suitable material for dynamo brushes. It is capable of withstanding high temperatures, it is a reasonably good conductor of heat and electricity, it is not unduly abrasive, and its "contact drop" although not high enough to cause excessive loss is sufficient to render possible a fixed brush position.

A demand is not infrequently made for a universal brush, or at most two qualities which will meet every case of commutating work, with a third quality for slip-rings. The requirements of modern machines, however, are too diverse and too exacting for such a thing to be practicable.

The function of a slip-ring brush is to maintain uninterrupted contact with the slip-ring, thus affording a means of passing current between the fixed and rotating parts of a machine. In the case of commutating machines the problem is greatly complicated by the fact that the brushes, in addition to having to perform the purely mechanical function of completing the electrical circuit, are called upon to assist in effecting commutation. It is true that the wide adoption of commutating poles has reduced the duties devolving upon the brushes from the commutating point of view, but it has by no means eliminated them. Nominally, commutating poles produce a flux proportional to the load; actually they do not. The use of a distributed compensating winding in addition to the commutating poles is restricted in practice to turbo dynamos and a few machines designed for specially severe conditions, such as rolling-mill work. With no compensating winding the ampere-turns required to neutralize the armature ampere-turns as well as those required to produce the commutating field must be concentrated on the commutating poles, with the result that the latter carry a very heavy winding which produces a correspondingly large leakage flux at heavy loads and therefore more or less saturation in the poles. The consequence is that the commutating flux is correct at one value of load only, and the contact resistance of the brush is necessary to limit the short-circuit currents at other loads.

Commutating poles are fitted not merely to improve commutation but also with a view to obtaining the maximum output per pound of material used. It naturally follows that the armature ampere-bars per centimetre of circumference have been increased and commutators have been reduced in dimensions. There is also a temptation to reduce the number of segments. This not only raises the total reactance voltage and therefore the portion to be dealt with by the brushes, but also increases the voltage per segment. Furthermore, distortion of the main field is not prevented by the use of commutating poles, so that under large fluctuations of load, with the consequent high maximum voltage between segments, a flash-over is liable to be caused. This is not directly a brush trouble, but it does limit the choice of grade to a very clean-running quality, as a mere trace of dust may provide the slight assistance necessary to cause the flash-over.

Again, the wide adoption of 50- and 60-period rotary converters produces difficulties inherently connected with the high frequency. Thus, if the frequency is 50, the time available for a segment to travel from positive to negative brush is 1/100 of a second; hence, if the peripheral speed is low, either the segments must be very narrow or the bars very few in number and therefore the voltage per segment high. The former gives a short flash-over distance, a relatively poor commutator mechanically, and a large percentage of mica, which is always a troublesome feature. If the number of segments is reduced to a minimum the liability to flash over is increased. On the other hand if these alternative difficulties are obviated by adopting a high surface speed, we are faced with the increased difficulty of maintaining perfectly uninterrupted contact between the brush and the revolving commutator.

Special machines such as low-voltage aero dynamos and magnetos have brought in their train their own particular brush problems, demanding the development of special grades to meet the case in question.

To secure satisfactory operation, then, the problem may be stated thus:—

(*a*) In the case of slip-rings the brushes must maintain uninterrupted contact with the rings and carry the current with minimum frictional and electrical losses. Distribution of current between the various brushes must be sufficiently uniform to prevent local heating, and the rate of wear of both rings and brushes must be kept within reasonable limits.

(*b*) In the case of commutating machines the problem is further complicated by the fact that the brush, instead of running on a smooth continuous homogeneous surface, must run satisfactorily on a composite surface consisting of narrow copper strips separated by mica or air spaces. Furthermore, the brushes must possess the commutating characteristics necessary to give the required assistance in this direction, and must be capable of withstanding the unequal distribution of

current which inevitably occurs in each individual brush.

### Properties of Carbon Brushes.

In the manufacture of carbon brushes there are many properties both electrical and physical that must be carefully watched and controlled. A well-equipped laboratory is therefore an absolute essential if consistent results and uniformity of product are to be maintained. The properties must be studied individually and then collectively by running the brushes under actual operating conditions. By this means a definite relation can gradually be established between purely laboratory results and actual running performance.

In this paper the word "collector" is used as a common term to denote either commutator or slip-rings.

The terms "positive" and "negative" are used in a motor sense; that is to say, by "positive brush" is meant the one by which the current passes to the collector, and by "positive ring" is meant the ring under the positive brush.

*Specific Resistance.*—Given suitable instruments, this is a very easy test to make and a very useful one to the brush manufacturer as a check upon uniformity. The resistance of graphite and carbon grades varies from a minimum of about 0·0003 ohm per inch cube to a maximum of about 0·0030 ohm per inch cube according to the proportion of graphite and other materials. Even taking the highest of these figures, the actual loss due to the resistance of the brush is only about 10 to 15 per cent of the loss caused by friction and contact resistance.

Thus in a brush 2 inches long × $1\frac{1}{4}$ inches × $\frac{3}{4}$ inch, having a specific resistance of 0·0020 ohm per inch cube and working at 40 amperes per square inch, the loss due to the resistance of the material would be only 6 watts, and even if the heat were dissipated by radiation only from the surface of the brush in still air the resulting temperature rise would be only about 30 degrees C. With the cooling facilities actually obtaining in practice, the temperature rise would probably not exceed 5 degrees C.

The specific resistance has a much smaller influence in determining the carrying capacity of a brush than the contact drop, coefficient of friction, and thermal conductivity of the material.

If a small proportion of copper is added, the effect is actually to increase the resistance, though the alteration in the nature of the contact surface thereby produced may nevertheless prove very beneficial. By increasing the copper content the specific resistance may be reduced to about 0·000005 ohm per inch cube, there being still sufficient graphite in the brush to have a marked lubricating effect.

*Friction.*—A low coefficient of friction is a matter of vital importance with the high peripheral speeds of modern machines, which sometimes approach, if they do not actually reach, 10,000 feet per minute. Apart from the actual loss incurred, if the friction is high it may (though not invariably) lead to chattering of the brush, and this is liable to cause chipping at the contact surface and breakage of flexible conductors. An imperfect contact between the brush and the collector, even if it does not produce destructive sparking, will at least increase the contact drop, so that the high friction increases the commutator loss directly, and also indirectly, by increasing the $I^2R$ loss. It may be mentioned in passing, however, that chipping and breaking at the contact surface are not by any means always attributable to high friction.

The coefficient of friction ($\mu$) is influenced by the brush material, the composition of the collector, the condition of the surface of the latter, the pressure on the brush, the peripheral speed, and the condition of the atmosphere. The author has read a statement that $\mu$ may easily be increased 25 per cent by heating, and again elsewhere that $\mu$ decreases with an increase of temperature. In the light of his own experience he is of the opinion that no temperature variations likely to occur in practice affect the coefficient of friction. An exception should perhaps be made in the case of a carbon brush heated at the contact surface to the glowing point. The local heating may be so intense as to graphitize the surface partially. This would naturally alter the coefficient of friction, but this is an altogether abnormal condition of operation.

The passage of current through a brush alters the nature of its contact surface and, in this respect, affects the friction. Samples for test should therefore be bedded with current flowing. After the surface appears to have been completely formed the first readings may be taken, but the test proper should continue for not less than three days with the machine running night and day. This gives the brush time to settle down thoroughly.

The effect of a variation in the pressure applied to the brush is very marked. If the pressure is increased from, say, 2 to 4 lb. per square inch the friction loss is very much more than doubled. The explanation of this apparent increase in the coefficient of friction (which may be anything from 10 to 100 per cent) is not obvious but may be due perhaps to some kind of suction effect. That a partial vacuum is sometimes produced under a brush there seems little doubt. Instances have been met where a considerable friction loss has been measured after the applied mechanical pressure has been carefully reduced to zero. In such cases the brush will be found to be "sticking" to the collector and a perceptible pull is required to remove it. If the brush and pressure finger are replaced and another reading taken immediately, a much lower value is obtained. It seems reasonable to suppose that this effect would be more likely to be produced with a heavy mechanical pressure than with a light one. Moreover, experience shows that it is more difficult to obtain consistent friction readings when the pressure is heavy than when it is light. The suction effect is more particularly in evidence with brushes that have developed a highly glazed surface, and it has even been observed on a commutator with recessed mica. The phenomenon is probably confined more or less to the laboratory where the friction machines are maintained in specially good condition, and no doubt under normal working conditions there is sufficient vibration to prevent its occurrence.

The peripheral speed has a pronounced influence upon the coefficient of friction, the latter falling with an increase of speed, though not always to the same extent. Fig. 2 shows an instance in which the effect of speed variation upon the coefficient of friction is very great. An inspection of the curve reveals that the total friction loss was actually greater at the lowest speed than at the highest. It seems probable that this decrease of $\mu$ with increasing speeds is due to a film of air between the brush and the collector.

Extraordinarily steep $\mu$ curves are occasionally obtained in the laboratory, and it is difficult to explain them except upon the hypothesis that at a very low speed the conditions are favourable for the development of what has been described as a suction effect, and that at high speeds the friction is reduced by a film of air under the brush. These phenomena are referred to again under "Contact Drop."

The primary object of laboratory friction tests is to obtain correct relative values between different grades, and in order to do this the apparatus used should be kept in first-class running order and the atmosphere should be free from dust. In ordinary working, less favourable conditions may obtain and the friction loss may therefore be higher.

*Contact Drop.*—The contact drop of a copper gauze brush is of the order of 0·2 volt. With a carbon brush

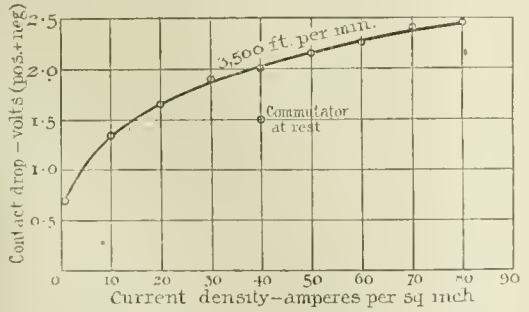


Fig. 1.—Contact drop of carbon brush containing no graphite. Pressure 2 lb. per square inch.

this is increased some 4 or 5 times, and from the efficiency point of view the carbon brush is at a disadvantage in this respect compared with the copper gauze. On the other hand, this contact drop is the most valuable property a carbon brush possesses. To quote the late Professor S. P. Thompson, "its presence is the whole secret of success in natural commutation. The price paid for the sparkless working of the machine is the voltage drop of 1·6 to 2 volts."

The voltage drop at the contact does not vary proportionally with the current but remains remarkably constant over a wide range, and there is for each quality of brush a critical value below which no current will flow. In this respect the behaviour somewhat resembles that of an electric arc, where there is a certain minimum voltage below which the arc cannot be maintained.

Fig. 1 shows the contact drop of a carbon brush containing no graphite. It will be seen that for the grade in question the minimum total voltage that will pass any measurable current is 0·7 volt. The curve rises very abruptly to 1·65 volts at 20 amperes per square inch. Between 20 and 60 amperes per square inch (which may be considered the working range of this brush) the contact drop rises only a further 0·6 volt. In other words, with an increase of 200 per cent in current density the contact drop is increased only 36 per cent. This curve was taken at 3,500 feet per minute. One test point is plotted showing the contact drop at 40 amperes per square inch with the machine at rest. It will be seen that this is considerably lower than at 3,500 feet per minute, but over a range of, say, 2,000 to 5,000 feet per minute the contact drop is practically unaffected by the collector speed. Above 5,000 feet per minute there is a tendency for the contact drop to rise slightly. An exceptional case is depicted in Fig. 2. This shows the coefficient of friction of a pure graphite brush at various speeds. The curve is so steep and the value of $\mu$ so low at the highest speeds as to suggest the air-film explanation mentioned above. Contact-drop readings were taken at the same time as the friction readings and these also are plotted. A

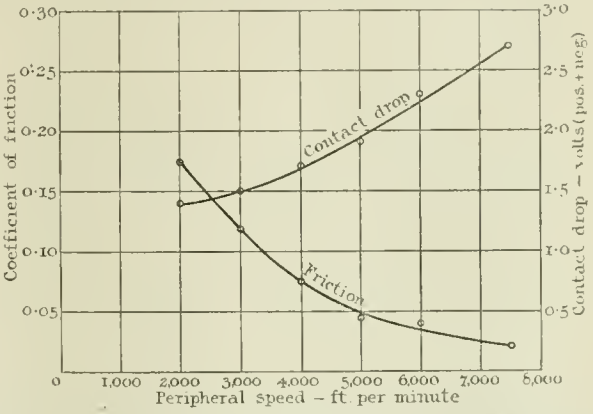


Fig. 2.—Coefficient of friction and contact drop at 40 amperes per square inch of a pure graphite brush. Pressure 2 lb. per square inch.

large increase occurs in the contact drop as the speed approaches the maximum, again suggesting the presence of an air film. These combined effects are more pronounced in this particular test than in any other that has come under the author's observation, but the instance is considered of interest as affording support to the explanation offered.

The immediate effect of an increase in temperature is usually a reduction in contact drop, but the extent is difficult to determine because the increase in temperature accelerates oxidation of the collector and this increases the contact drop. Many tests have been made but it is not easy to obtain consistent results. The testing machine was enclosed in a glass-covered box and a heating coil arranged under the rings for controlling the temperature. Some tests have been made with the rings running at 3,500 feet per minute, and with a view to eliminating some of the variables others have been made with the rings at rest. Starting with perfectly clean rings, generally speaking a drop of about 20 per cent occurs very shortly after switching

on. The contact drop then rises much above the original value. On cooling again, the behaviour is uncertain but the contact drop does not return to anything approaching the original value. After cleaning the rings with fine glass paper without disturbing the contact surface of the brushes, a further test reveals a large reduction of contact drop.

The behaviour of graphite brushes appears to be more consistent than that of carbon. In the case of the latter it has sometimes been observed that no initial decrease in the contact drop occurs. Actual figures relating to a test on pure graphite brushes are given below; the current density was 60 amperes per square inch, pressure 4 lb. per square inch, rings stationary. The arrangement for supporting the brush was such that practically no heat could be dissipated by conduction from the brush except into the ring, so that the temperature of the brush rose very quickly. In taking the readings in the last column a little time was lost in getting everything steady, with the consequence that the brushes reached a considerable temperature though the rings were still practically cold. The readings in this column thus correspond approximately to those in the second column:—

Contact Drop in Volts (Graphite Brush).

| *Start* | *After 2 min.* | *After 58 min.* | *After Cooling.* | Rings cold after cleaning |
|---|---|---|---|---|
| Rings 25° C.<br>+Brush 25° C.<br>−Brush 25° C. | —<br>+Brush 50° C.<br>−Brush 49° C. | Rings 90°C.<br>+Brush 150°C.<br>−Brush 140°C. | —<br>+Brush 52° C.<br>−Brush 47° C. | —<br>+Brush 64° C.<br>−Brush 65° C. |
| +0·82 | 0·65 | 1·08 | 1·30 | 0·50 |
| −0·68 | 0·62 | 0·72 | 0·84 | 0·68 |

In actual practice, considering the combined effects of an increase in temperature per se and the resulting

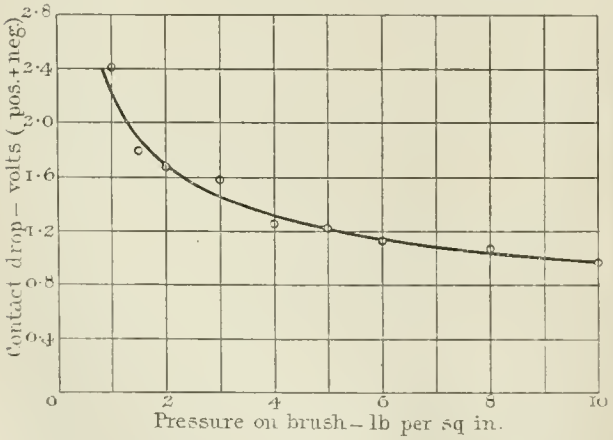


Fig. 3.—Contact drop of carbon brush containing no graphite. Current density 40 amperes per square inch. Speed 3,500 ft. per min.

oxidation, it seems highly improbable that any large reduction in contact drop occurs, otherwise we should have an unstable condition of things, since the contact resistance forms such a large proportion of the entire brush resistance. If an increase of temperature produced a decrease in the total brush resistance, to

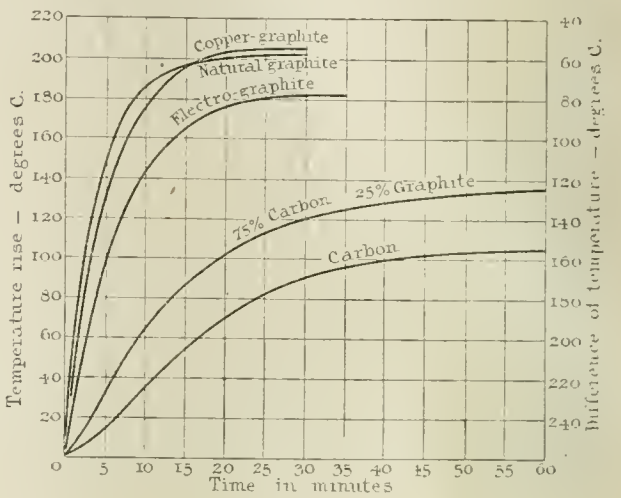


Fig. 4.

attempt to run brushes in parallel would be similar to attempting to run compound dynamos in parallel without equalizers.

The contact drop is very definitely affected by the amount of pressure applied to the brush. A typical curve is shown in Fig. 3, which refers to a carbon brush. The test was made at 40 amperes per square inch, the speed being 3,500 feet per minute. The bearing this has upon operation is considered later under "Selection of Grades."

*Thermal Conductivity.*—The thermal conductivity has a very definite bearing upon the performance of carbon brushes, as relatively very large amounts of heat are generated in very small volumes of material, and unless the heat escapes rapidly a destructive temperature rise is the result. Consider the losses occurring in a carbon brush 2 inches × 1¼ inches × ¾ inch, assuming that the technical data referring to the grade in question are as follows:—

| | |
|---|---|
| Specific resistance .. .. | 0·0020 ohm per inch cube. |
| Contact drop at rated current | 1 volt. |
| Coefficient of friction .. | 0·20 |
| Current density .. .. | 40 amps. per square inch. |
| Peripheral speed .. .. | 3,000 feet per minute. |

The losses will then be as follows:—

| | | |
|---|---|---|
| Loss due to Resistance of the brush .. | 6·0 | watts |
| ,, Contact drop .. .. | 37·6 | ,, |
| ,, Friction (at 2 lb. per square inch) | 25·4 | ,, |
| Total .. .. .. | 69·0 | ,, |

Thus over 90 per cent of the loss occurs at the contact. Unequal distribution of the current, overloads,

and circulating currents, all tend to increase and localize the heat still more.

The thermal conductivity of the various classes of brushes varies very largely. It is greatest in the pure graphite and highly metallic copper-graphite brushes, and least in the carbons. In Fig. 4 are shown the results obtained by heating blocks of various materials at one end and measuring the temperature rise at the opposite end. The blocks were 4 inches × 1 inch × 1 inch. They were uniformly lagged with asbestos, with the exception of $\frac{1}{4}$ inch which was left bare at one end. A hole was drilled at the opposite end to take the bulb of a thermometer. The bare end was then dipped in solder, which was maintained at 260 degrees C., above the atmospheric temperature. Temperature readings were taken at the top end and the curves show the rate of rise and the final difference of temperature between the two ends of the samples. It will be seen that the temperature rise at the end of three minutes and the final difference of temperature between the two ends are as follows :—

| | Temperature Rise after 3 min. | Final Difference of Temperature between the two Ends |
|---|---|---|
| | Degrees C. | Degrees C. |
| Carbon .. .. .. | 6 | 152 |
| 75 per cent carbon, 25 per cent graphite | 16 | 124 |
| Electro-graphitic .. .. | 60 | 78 |
| Copper - graphite (highly metallic) | 92 | 56 |
| Pure natural graphite .. | 105 | 58 |

Under working conditions the heat generated at the contact surface is dissipated partly into the collector, and partly into the brush and therefrom to the holder by direct contact and also via the flexible.

It is clear from the thermal curves that for a given contact loss a brush made of carbon is likely to reach a much higher temperature near the contact surface than one made of natural or artificial graphite. If a pure carbon brush is suddenly called upon to carry an excessive current the temperature at the contact surface is liable to be raised to glowing point, with the result that the latter is burnt. Graphite brushes, on the other hand, owing to their greater thermal conductivity are able to carry correspondingly heavier loads without such a high temperature being reached.

Incidentally this great difference in thermal conductivity explains the observed fact that flexible conductors in graphite brushes are more liable to burn out than the flexibles in carbon brushes.

*Hardness and Abrasiveness.*—These two terms are frequently confused, whereas in reality there is a very definite distinction between them. By the former is meant the degree to which the material resists permanent deformation, and it may be measured conveniently by means of a Shore scleroscope, or rough comparisons may be made by scratching tests. A brush may be very hard and yet only very slightly abrasive. Frequently a harder brush is asked for, when what is required is either a more refractory brush or a more abrasive one.

The purely mechanical abrasive action of the majority of brushes is very slight indeed, and in some instances it may be necessary in the course of manufacture to incorporate a small quantity of abrasive material to prevent a brush from smearing the collector.

Tests made with no current flowing, however, reveal that even the last-mentioned brushes do not produce very rapid collector wear by abrasion. The following figures relate to tests made upon bronze slip-rings, the test brushes being 1 inch thick circumferentially, mounted one per ring. The pressure was 4 lb. per square inch ; peripheral speed about 4,000 feet per minute ; duration of test 20 million revolutions.

| Description | Radial Wear of Rings per 20 million revs. |
|---|---|
| Pure graphite | Less than 0·001 mm. |
| Carbon (non-abrasive) | ,, 0·001 mm. |
| ,, (abrasive) | 0·070 mm. |

The most abrasive of these brushes is not a type that would be fitted upon high-speed machines but might, for instance, be fitted upon a 4-pole motor running at 800 r.p.m. Assuming the brushes to be $\frac{1}{2}$ inch thick with four mounted on each track of the commutator, then on the basis of the figure in the table to produce a radial wear of 1 inch on the commutator the machine would have to run 10 hours a day for 21 years, and this with a pressure double that to be expected in practice. The influence that the passage of current has upon the rate of wear is dealt with later.

*Inertia.*—For very high-speed work the problem largely consists in maintaining contact with the collector. By reducing to a minimum the inertia of the moving parts, including the brush material itself, assistance in this direction is obtained, as the brush when it shows a tendency to leave the collector is more rapidly returned to its work by means of the pressure spring.

### Design of Brush.

*Size.*—The use of large brushes effects economy in holders, but a moderately small brush gives much more satisfactory operation. If the brush is very small, unnecessary multiplication of parts ensues, but if a moderate size is adopted several important advantages are secured. The brushes bed independently ; if one brush is disturbed it means a smaller proportion of the whole ; and the cooling conditions are improved. It is suggested that for ordinary commutator work the brush width should not be greater than $1\frac{1}{4}$ inches,

and the thickness should be that required by the commutating conditions, but preferably not more than 1 inch.

Brushes of the slide type are immensely superior to the grip type, owing to their lower inertia and consequent ability to respond readily to inequalities in the collector. An exception may be necessary in the case of induction-motor brushes which are lifted after the motor has been run up to speed; but in this case the need for a slide type is largely eliminated by the fact that the brushes are only in service for a few moments at a time.

*Fittings.*—A brush should be reduced as far as possible to its simplest elements and all unnecessary fittings avoided which add to the inertia of the brush and are seldom essential to its satisfactory operation. If any protection is required on the top of the brush it should take the form of insulating material; this is lighter than metal and is more effective for the purpose, as the excessive wear sometimes produced on the top of a brush by the pressure finger is more an electrical effect than a mechanical one. Suitable insulating material prevents the passage of current through the finger and, incidentally, through the spring as well, and it is more capable than metal of withstanding the wear of the finger. Solder should be avoided whenever possible, as under exceptional conditions it is liable to melt and run on to the commutator.

Copper plating is a necessity with some types of connections, and certain classes of brushes cannot be made to possess the requisite characteristics without making them comparatively fragile; in such cases an envelope of copper materially strengthens them. Coppering, however, has its attendant disadvantages. The brushes must have sufficient clearance in the holders over the coppered portion and therefore an undesirable amount of clearance over the un-coppered portion. Copper plating on a brush also encourages the current to pass directly from the sides of the brush to the holder. This causes rapid wear of the brush boxes, and the excessive clearance resulting therefrom prevents a brush from bedding perfectly on the collector if it does not actually lead to serious chattering and breakage of the brush. In the author's opinion it is almost impossible to exaggerate the importance of making the mechanical conditions as perfect as possible. Half the battle is to maintain intimate contact with the collector. The total clearance in the holders should not exceed, say, 0·2 mm. in the circumferential direction and 0·3 mm. in the axial direction, and these figures may be halved with advantage. The brush boxes should be deep and should have four complete sides with unbroken surfaces; that is to say, there should be no slots or holes which can cause the brushes to hang up in the boxes. Flimsy holders are poor economy; they are usually very inaccurate and vibrate excessively under adverse conditions. Substantial cast holders are a great assistance to satisfactory operation. They can be made very accurately, they resist any tendency to chatter, and they form a valuable means of dissipating the heat generated at the contact surface of the brushes, especially if the holders are set close to the commutator, as they should be.

The endless variety and design of holders illustrates the diversity of opinion on this subject, but for high-speed work the majority of constructors have adopted the type which embodies a spiral spring directly behind the brush. This type possesses the additional advantage of taking up a minimum amount of room in the circumferential direction, and therefore affords a minimum of assistance to an arc to maintain itself between spindles of opposite polarity.

Every brush should be fitted with flexibles proportioned to carry full current with a reasonable margin for overloads and unequal distribution of load. On the other hand, the flexibles should not be larger than is necessary, especially if they are short, as they tend to make the brush sluggish in its holder. A shoe-type terminal should be used which can be positively clamped under the head of a screw. Pin-type terminals which are simply pushed into a round hole make very uncertain contact and cannot be recommended.

For many years traction brushes were rarely, if ever, fitted with flexibles, the pressure finger and box sides being depended upon to carry the current. The reason for this seems to have been largely due to the difficulty of providing satisfactory means of securing the terminal end of the brush to the holder. This has been solved by a form of spring grip which can be operated in inaccessible positions and has no parts that can work loose and cause damage inside the motor. The use of flexibles increases the life of both brush and commutator, wear at the top of the brush is prevented, and an all-round better performance is obtained.

### Selection of Grade.

The available grades of brushes may be divided into four classes: graphite, carbon, electro-graphitic and copper-graphite. The first mentioned consist of practically all natural graphite and are distinguished by their very high electrical and thermal conductivities and low coefficient of friction. Their sphere of use is primarily on high-speed commutators and on slip-rings if the current density and radiating surface permit.

The carbon grades may contain a considerable proportion of graphite at one end of the series, diminishing to no graphite at all at the other end. Generally speaking they have a higher contact drop than graphite brushes.

The electro-graphitic brushes are made from carbon which after kilning is converted (including the binding material) into artificial graphite in the electric furnace. The characteristics of the material are radically changed by this treatment. The electrical and thermal conductivities are greatly increased, and the material becomes softer, yet can be made very tough. It also becomes very much more refractory; such brushes are therefore specially useful where circulating currents are excessive or overloads severe, and it naturally follows that this class is largely used for traction work, especially upon single-phase commutator motors. Heavy circulating currents can be controlled to a certain extent by using a high-resistance brush, but it not infrequently happens that the surface of the brush is cratered or eaten away by the action of such currents, and it is then necessary to employ a highly refractory

brush capable of carrying them without damage to itself.

The copper-graphite brushes contain copper, with or without other metals, and graphite to the extent of from 5 to 60 per cent according to the properties desired. This series of brushes is required for slip-ring work and to a certain extent for low-voltage plating and similar dynamos. It is characterized by its low contact drop and high carrying capacity.

*Current Density.*—The most important property of a brush is its current-carrying capacity. It must be recognized, however, that the actual current in a brush is usually very different from the nominal, owing to the large number of disturbing influences.

If two copper conductors of equal length are coupled in parallel the current will divide in proportion to their sectional areas (neglecting any slight disturbance that may be caused by difference in temperature) since the voltage drop is proportional to the current density. In the case of carbon brushes in parallel, however, this regulating influence is largely absent. The two parallel paths each consists of contact, brush material, connection of brush to flexible, flexible, and terminal connection. The contact resistance is normally greater than the sum of the other four components, and it has already been seen that the contact drop is by no means proportional to the current. A roughness on the commutator, a little dust under a brush, or some similar cause might easily raise the contact-drop curve of an individual brush sufficiently to cause it to take only half as much current as its neighbour.

Another fruitful cause of unequal load distribution is unequal pressure applied to the brushes. Fig. 3 gives a curve of contact drop plotted against pressure applied to the brush. The same positive brush as was used in that test was also tested for contact drop at various current densities, first at $1\frac{1}{2}$ lb. per square inch and then at 5 lb. per square inch. The resulting curves are drawn in full lines in Fig. 5.

Now consider the case of two sets of brushes, say 2 inches long × 1 square inch section operating in parallel. The total drop in the terminal, flexible connection, and material, at 40 amperes per square inch would be about 0·2 volt and would vary directly as the current. The broken line curves in Fig. 5 include this extra drop and thus show the total brush drop at $1\frac{1}{2}$ and 5 lb. per square inch respectively. If the two brushes were nominally working at 40 amperes per square inch, it is evident from the curves that the total current of 80 amperes would be divided between the two brushes in the proportion of 24 to 56. It is not uncommon in practice to meet with variations of pressure as great as $1\frac{1}{2}$ to 5 lb. on the same machine. The different brushes on one spindle or on one slip-ring may share the load very unequally, and with a wave-wound armature for the same reason there may be very unequal distribution of load between spindles of the same polarity. Again, in practice we do not get ideal straight-line commutation, with the result that the distribution of current across the face of the brush is very unequal, in fact, very often an actual reversal of current occurs, current flowing into the brush at one part and out at another. If any further proof of the unequal distribution of current across the face of the brush is needed we have it in Professor Miles Walker's split-brush device, which depends for its operation upon the unequal and varying distribution of current across the face of the brush.

The carrying capacity of a brush is determined by its permissible temperature rise. The loss in the brush obviously does not depend solely upon the nominal current, and furthermore the facilities for dissipating the heat generated are very indeterminate; it follows, therefore, that any figures given in brush manufacturers' schedules can only afford an approximate guide and their chief value is relative. Indeed, the latter may be said of all brush data, since the brush itself is only one of many factors entering into the problem.

*Peripheral Speed.*—With the advent of turbo dynamos, peripheral speeds have reached very high values. In fact, in the case of turbo-alternator rings the peripheral speed sometimes appears to be unnecessarily high. The diameter of the rings is sometimes made larger

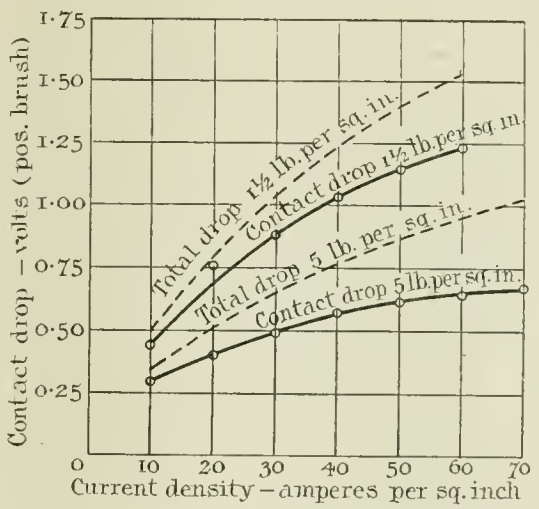


Fig. 5.—Contact drop of carbon brush containing no graphite. Speed 3,500 ft. per min.

than the shaft demands, and there is certainly no need to increase the diameter in order to obtain sufficient radiating surface to dissipate the heat.

To meet the altered conditions introduced by turbo machinery it has been necessary to develop new grades. The characteristics required are a low coefficient of friction, high carrying capacity, and absence of abrasiveness, also, preferably, low inertia as well. This restricts our selection to brushes in the graphite class.

*Mica.*—Mica is admittedly very variable in quality and greatly complicates the problem. Owing to the impossibility of getting large sheets of pure mica, built-up mica is used in all but very small commutators. This precludes the possibility of a hard spot extending right through the sheet, and in this respect the built-up article is to be preferred to the pure sheet. On the other hand, excess of the adhesive used may lead to trouble, as noted in a later section of this paper. If the mica is not recessed the brush selected must be sufficiently abrasive to keep the mica flush. Owing

to the varying quality and percentage of mica in the commutator it is not always easy to secure the exact degree of abrasiveness required, and if the brush is either too abrasive or insufficiently abrasive excessive wear of the segments will result. On high-speed commutators (and be it noted the majority of brush problems are concerned with such) the mica is invariably recessed. This relieves the brush from the duty of grinding down mica; it must be clean running, but need not be actually abrasive.

*Slip-rings.*—In the case of rings the composition of the material used has an important bearing upon the behaviour of the brushes. Many mixings have been tried and doubtless there is little to choose between several, but it may be mentioned that Admiralty gun-metal (88 per cent copper, 2 per cent zinc, 10 per cent tin) has been found excellent in every way. Steel is used sometimes for turbo-alternator rings and occasionally malleable iron for induction motors. These metals possess marked disadvantages. Their thermal conductivity is lower than that of bronze, with the result that the heat generated at the contact surface of the brushes is not so readily conducted away. Also, even when clean the contact drop with iron or steel is some 30 per cent greater than with bronze. The rings tarnish very readily if left standing for a short time, and the contact drop is then still further increased. Moreover, the tarnish is not uniformly distributed round the ring owing to certain parts being covered by the brushes when the machine is at a standstill, with the result that "flats" are very apt to develop.

If the current to be collected is large, low contact drop becomes of special importance, and in order to secure this a highly metallic grade must be chosen. If the current is comparatively small, however, and the ring surface relatively liberal, it is frequently advantageous to use a pure graphite brush. These brushes are cheaper in first cost, afford more perfect lubrication, and in consequence cause less dust and wear. Moreover, any dust produced is of a less dangerous character than metal dust.

*General.*—Laboratory tests are of great assistance, especially when studied in relation to the performance of the grade under actual operating conditions. With the help of the necessary data relating to a machine, it is usually possible to select a suitable grade. What is one man's meat is another man's poison, however, and, similarly, machines exhibit curiously marked idiosyncrasies and demand brushes to suit their individual tastes. Two machines may be made at the same time and to the same specification and yet it may be found impossible to use the same grade on both. It follows therefore that the ultimate test as to suitability must be made on the machine itself.

### Operation.

*Angle.*—The tendency to chatter is reduced by operating the brush either reaction or trailing, i.e. by tilting either against or in the direction of rotation. There appears to be no universally best angle for the brush, and the diversity of practice bears this out. Experiments have shown, however, that if the brushes are set trailing, the angle from the radial may advantageously be from 5 to 15 degrees, whereas if the brushes are set reaction, it should be considerably larger, say from 20 to 35 degrees. When the angle approaches the maximum it is advisable to round off the sharp edge of the brush to prevent it from digging into the edge of the approaching segments.

The holders, as already noted, should be set as close as possible to the commutator, say $\frac{1}{8}$ inch therefrom. This affords a valuable means of cooling the tip of the brush.

*Bedding.*—This is an operation that is frequently carried out in a most slipshod manner. The machine is frequently run up to full load when the brushes are less than half bedded, and the latter are expected to operate satisfactorily though the current density may be several hundreds of amperes per square inch. There are many disturbing influences which can be controlled to only a very limited extent, so that there is all the more reason to ensure that the brushes are well bedded, as bad bedding is a defect that can easily be eliminated. The work should be finished with fine carborundum cloth pulled across the face of the brush in the direction of rotation. After bedding, all dust should be carefully removed. The machine should then be run on "no load" for some time and the current gradually increased so that it is not out of all proportion to the amount of the contact between brush and collector. The pressure, for reasons already touched upon, should be as uniform as possible, and a suitable spring balance should be used for definitely measuring this. The two primary difficulties in operating brushes are to maintain intimate contact between brush and collector and to ensure a reasonably equal distribution of current between the various brushes. Fig. 3 shows that to prevent the latter trouble arising the pressure must be made uniform throughout. The actual value should, generally speaking, be the minimum required to maintain efficient contact between brush and collector. This will vary from $1\frac{1}{2}$ lb. in a well-balanced turbo dynamo to about 2 lb. in an ordinary industrial motor; whilst in a traction motor subject to severe vibration the pressure required may be as much as 6 lb. per square inch, or even more. To prevent the formation of ridges on the commutator the brushes should be staggered. The correct method of doing this is explained later with reference to Fig. 7.

*Mixing Grades.*—Here again the guiding principle of doing all that is possible to secure a uniform distribution of current must be borne in mind, and it is therefore highly inadvisable to mix different grades indiscriminately on the same machine. It is impossible to determine the relative merits of the grades mounted if they are mixed. Often the one that behaves worst is the one that would give the best results if used alone. Occasionally with difficult commutating machines or with very low-voltage dynamos it may prove advisable to mount brushes of one quality in all the positive holders and another quality in all the negative holders. Also in the case of slip-rings a few graphitic brushes are sometimes mounted on the same ring with metallic brushes. In such cases it must be realized that the sole function of the graphite brushes is to lubricate the ring. Owing to their contact

drop being so much higher than that of the metallic brushes they will carry no current, and therefore incidentally there is no need to fit such brushes with flexibles. This is clearly illustrated in Fig. 6, which shows the contact-drop curve of a copper-graphite brush taken on a slip-ring with alternating current, and also of a pure graphite brush taken on the same machine, the pressure, speed, etc., being the same in both cases. It is clear from these curves that the copper-graphite brush will carry any reasonable current with a contact

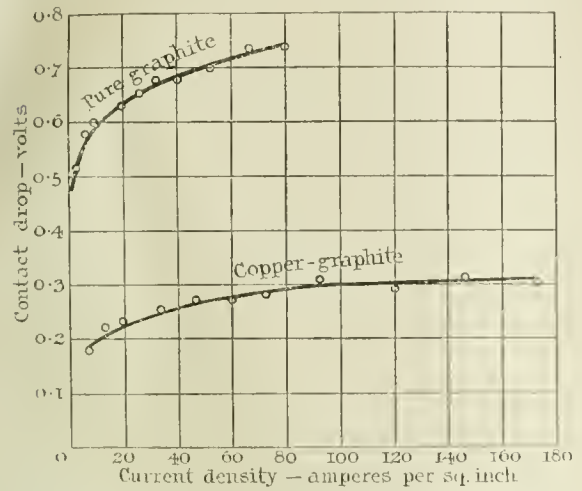


FIG. 6.—Contact drop of a highly metallic copper-graphite brush and of a pure graphite brush. Speed 4,500 ft. per min. Pressure 2 lb. per square inch.

drop of less than 0·4 volt, whilst the graphite brush will carry no current with a drop of this value.

*Rate of Wear.*—The wear of the collector is due to three causes: mechanical abrasion, a kind of electrolytic action, and burning away of the metal. The rate of wear of the collector is dependent upon the material it is made of, the quality of the brush, the current density, and the intimacy of contact between the brush and collector. In ordinary practice the last mentioned is the most important factor, and in the case of commutators is largely influenced by the mica. The latter, as previously mentioned, is a very variable product. It is the cause of much anxiety to the brush manufacturer and lies at the root of many commutation troubles. Until the advent of modern high speeds, mica was rarely if ever recessed between the segments, and the brush, in addition to its other duties, was called upon to grind down the mica and keep it level with the copper. If the brush is too abrasive, obviously it will cause excessive mechanical abrasion. On the other hand, if it is insufficiently abrasive to keep the mica flush, copper picking is very likely to result, proud mica being one of the most fruitful causes of this troublesome malady. It is difficult to explain all the phenomena associated with copper picking, but that it is due to something akin to electrolytic action is clear from a consideration of the following:—

If a commutator is equipped with brushes arranged so that the positive and negative brushes sweep different tracks, and if the machine is run with no current, the two halves of the commutator will maintain the same appearance and the wear caused by abrasion will be relatively very slight. If current is then passed through the armature the portion of the commutator under the positive brushes (speaking in a motor sense) will assume a dark polished appearance, as though carbon or graphite from the brushes passed in the direction of the current and were deposited on the surface of the copper. The portion of the commutator under the negative brushes will retain a bright coppery colour and become more or less raw in appearance. The rate of wear under the negative brushes will be very much increased compared with that observed when no current is flowing, perhaps by several hundred per cent, showing that, due to the action of the current, particles of copper are passing away from the surface of the commutator in the direction of the current flow. The minute particles of copper passing in the same direction as the current usually do not adhere to the face of the brush, but sometimes they are firmly deposited on the contact surface as though the latter had been copper plated. It is difficult to determine exactly the conditions under which copper will be deposited on the brushes. Undoubtedly the action is promoted by lack of perfect contact between brush and commutator, and it increases with the current density. Poor contact may result from insufficient pressure, chattering, or more frequently from high mica. If in addition to poor contact between brush and copper the current density is high, the conditions are favourable for deposition of copper on the brush, and when once the first speck is deposited the process becomes cumulative. The contact resistance is reduced, causing the brush to take a larger share of the working current and also a heavier circulating current, owing to the resistance in the path of the latter being reduced. The mechanical scoring action is increased owing to the coating of copper on the face of the brush if the mica is not preventing contact. In practice the positive and negative brushes are arranged so as to sweep the same tracks, and the surface of the commutator assumes an appearance which is a mean between the two surfaces described above, but the action is still going on to a greater or less extent.

It may be remarked in passing, that when brushes are staggered to prevent the formation of ridges on the commutator this should be done so that each track is still swept by an equal number of positive and negative brushes. Fig. 7 shows the incorrect and also correct methods of staggering brushes.

The presence of circulating currents appears to account for the fact that positive as well as negative brushes are liable to become copper coated as circulating currents pass into each brush as well as out of it; in fact it is probable that if it were not for the circulating currents the current density in the brushes would seldom be high enough to bring about the conditions necessary for the deposition of copper, and this is borne out to some extent by the fact that machines fitted with interpoles much less frequently develop this trouble than non-interpole machines.

In individual cases where persistent copper picking occurs, an improvement may be effected by a change

in the quality of the brush on lines suggested by the above: but in general it is important to bear in mind that the "electrolytic" action should be reduced to a minimum, and this can be done to a large extent by ensuring good contact between brush and commutator, and by avoiding excessive current density whether caused by the working current or by circulating currents. It thus becomes apparent that the problem is closely connected with the design of the brush holder, the quality of the mica, the shape of the pole tips, and the various other factors determining the extent of the circulating currents, as well as the density in the brushes due to the working current.

In addition to the electrolytic action described, a certain burning action occurs, even when there is no visible sparking. This is dependent upon the intimacy of contact and the current density, and of course affects both positive and negative brushes. There is a very close connection between the current density and the life of

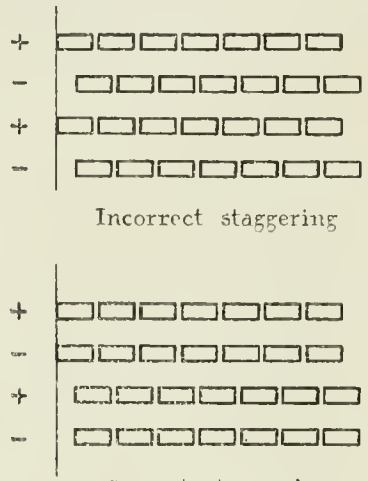


Fig. 7.

both the brush and the collector. By way of illustration, Fig. 8 shows the relative amounts of wear produced at various current densities by an ordinary carbon brush. The tests were made on bronze slip-rings. It is clear from these curves that if an absolutely non-abrasive brush were mounted on a commutator with perfectly flush mica, the copper would nevertheless be gradually removed from the face of the segments, leaving the mica standing proud. The process rapidly becomes cumulative. The more proud the mica becomes, the greater the rate at which the copper is removed from the face of the segments. Thus excessive commutator wear may be caused by the brushes being insufficiently abrasive to keep the mica flush. That this is so has been proved repeatedly by overcoming excessive commutator wear by deliberately replacing the brushes by another quality of a more abrasive character.

The wiser course to adopt with large machines, and the absolutely necessary course in the case of very high speeds, is to recess the mica. When this is undertaken, however, the work must be very well carried out or the results will be worse than before. Removing the mica has in itself a tendency to cause the brushes to chatter, and if the work is badly done this may be very marked. The depth of the groove should not be greater than the thickness of the mica, and the latter should be cleanly removed so as to leave a groove rectangular in section. The edges of the segments should then be very slightly bevelled. If the depth of the slot is excessive, oil and dirt are liable to collect, which may ultimately cause a breakdown. The slots should be regularly cleaned out, and for this purpose a scraper made of bone or some similar material is preferable to a steel scraper, as the latter is apt to dig into the copper.

When the mica is well recessed a high-grade non-abrasive graphitic brush may be used, and the wear of both commutator and brush is reduced to a minimum.

The rate of wear of the brush also is very largely affected by the current density. In Fig. 8 curves relating to pure carbon brushes are given which show how very marked this influence may be.

*Lubrication.*—The majority of modern high-grade graphitic brushes are practically, if not entirely, self-

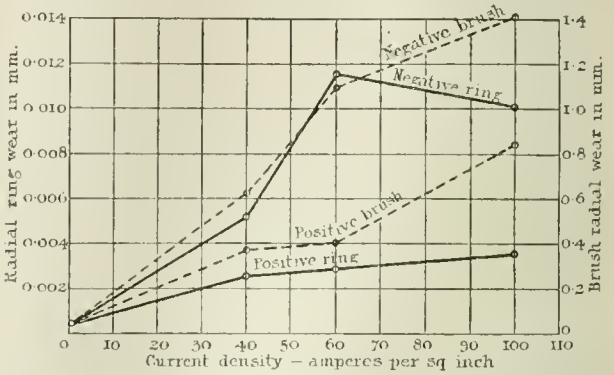


Fig. 8.—Wear of slip-ring and brush (carbon brush containing no graphite). Presure 4 lb. per square inch.

lubricating, and wherever possible it is advisable to abstain from applying lubricant to the commutator, as a more stable condition of affairs is thereby produced. This is also a matter of special importance if the mica is recessed, as oil has a very solvent action upon the adhesive used in making the built-up mica.

*Operating Conditions.*—The commutator, brushes, and brush gear admittedly constitute the most vital parts of a commutating machine, and it therefore behoves the engineer to bestow especial attention upon them, forming, as they do, the weakest link in the chain of conversion from mechanical to electrical energy, or vice versa. The same may be said with almost equal truth respecting slip-rings with their brushes and holders.

Some of the conditions under which brushes are called upon to operate are at times fundamentally difficult and cannot be altered, but frequently the conditions are rendered unnecessarily difficult through a lack of appreciation of the factors essential to successful operation on the part of the attendant rather than from mere wanton neglect.

Much has been written upon the subject of faults in operating electrical plant and their remedies, and it

is not within the scope of this paper to deal with these in detail. It may not be out of place, however, to emphasize the importance of close attention to what may appear trivial mechanical details, for experience shows that it is not as generally recognized as it should be how much the life of both brushes and collector may be increased and the general performance improved in this way. Undoubtedly it does pay to give a new set of brushes a good send-off, to see that the clearance is sufficient without being excessive, to adjust the pressure accurately by an intelligent use of a spring balance, and to bed the brushes thoroughly. The collectors should be made to run as truly as possible, and vibration due to loose bearings or want of balance should be reduced to a minimum.

Commutator surface speeds frequently reach 6,000 feet a minute and sometimes as much as 9,000 feet a minute, and the trend of design is in the direction of still higher peripheral speeds. Commutators are never mathematically circular and a very small mechanical defect is sufficient to cause a momentary separation between the brush and the collector. It is of vital importance, therefore, that the brush should be free to follow up any slight irregularities, and since a slight accumulation of dust is liable to cause a brush to stick, the question of clearance should be carefully watched, not only when the brushes are first mounted, but at regular frequent intervals.

A slight amount of dust is formed by mere abrasion; more is formed by the action of the current, especially if contact between brush and collector is poor. If this dust is allowed to accumulate in the holders the brushes will become sluggish, even if they do not actually stick. Sparking then occurs under the brush, accompanied by a transmigration of metallic particles from the "low" portion of the collector surface to the brushes, and what was merely a very slightly "low" place on the collector may rapidly develop into a flat. Thus close attention to the condition of the brushes and brush gear leads not only to a saving in time but also to a marked reduction in maintenance costs.

A large turbo dynamo equipped with over 100 brushes had been running perfectly for weeks. Suddenly it began to vibrate badly and spark violently. It was shut down at once and close examination revealed that the cause was solely due to one brush becoming stuck in its holder. As soon as this was freed the machine ran perfectly as before.

### Standardization.

From time to time this question, which is beset with difficulties, has been discussed in this country in an informal way, and at the present time definite recommendations are under consideration with regard to standard sizes of brushes for shipboard machines. In America greater efforts have been made in this direction. The Electric Power Club, after investigating the matter for many months, have recommended for general adoption certain standards. According to these recommendations there are five permissible standard lengths between the limits of $1\frac{1}{2}$ inches and $2\frac{1}{2}$ inches inclusive (to be reduced where possible to three). There are five permissible standard widths between the limits of 1 inch and $1\frac{1}{2}$ inches inclusive (to be reduced where possible to three), and there are 10 permissible standard thicknesses between the limits of 5/16 inch and 1 inch inclusive (to be reduced where possible to eight). Thus, even within comparatively narrow limits, there are 250 permissible standard sizes (to be reduced where possible to 72). This would appear to suggest that designers in America are of the opinion that very considerable latitude must be left to them in the selection of brush dimensions. The dimensions of the actual block, however, are only the beginning of the problem. There is the question of fittings to be considered. If brushes are really to be standardized as regards their mechanical design a certain degree of uniformity in the design of holders becomes necessary, so as to permit uniformity in the length and position of flexible and also in the type and size of terminal. When it comes to a question of quality this would appear to defy all efforts at standardization, except possibly on exceedingly broad lines. Even standardization of machine design would not completely eliminate the difficulties here, since the differences in brush properties are so subtle and yet so pronounced in their influence on the behaviour of a machine that it seems fundamentally impossible to harness them in a specification.

A certain measure of standardization is possible within prescribed limits. Any recommendations that could be applicable to all types of machines, however, must necessarily be on such very broad lines that they could scarcely be described as standardization. It is therefore wise to proceed by stages, including at first only the mechanical design of the brush and applicable only to machines intended for a certain class of work, such as motors and generators (excluding turbo dynamos) for shipboard use. This is the sphere in which the benefits of standardization would naturally make themselves most felt, and by proceeding cautiously in this way it may in time prove practicable to introduce recommendations of a more comprehensive character.

## Discussion before The Institution, 19 December, 1918.

**The President**: A Sub-Committee of the British Engineering Standards Association has at present in hand the question of the standardization of brushes. They are making a small beginning, as mentioned in the paper, in the direction of standardizing the sizes of brushes for use on board ship, but it is hoped eventually to go very much further than that and some day to prepare a specification which will enable brushes to be specified accurately instead of allowing them to be purchased in the very haphazard way by trial and error that exists very often at present. The author is a member of that Sub-Committee and we hope that with his assistance something will be done in the not very distant future.

**Mr. A. D. Constable:** The paper brings home to us how little we know about the apparently simple problem of collecting current from a moving surface. Most engineers think they know all about carbon brushes, but the knowledge of the carbon-brush expert is not always transferred to the drawing office of the manufacturer of the machines. Some of the peculiar results observed with carbon brushes appear to transgress the ordinary physical laws. I think there is one explanation for nearly all these occurrences, and it is mentioned in the last part of the paper, namely, that it is impossible to make a mathematically true commutator. One can easily see that with commutators running at a surface speed of about a mile a minute any small departure from accuracy will cause the brush to leave the surface, or at any rate will vary the pressure between the brush and the commutator very greatly. That explains the rapid drop of the coefficient of friction with increase of speed. I think that the idea of a film of air between the brush and the commutator is untenable, but that we get an intermittent contact so that there is friction at one instant and practically none at another. The increase of contact drop at high speed is also explained by this intermittent contact. We have a certain resistance at the time the brush is in contact; on passing the high parts this will naturally increase when there is less pressure, and much more so in the case of separation between the brush and the commutator. We also find that the increase in friction loss may go up very greatly if the pressure on the brush is slightly increased. I think the explanation of this effect is probably that the increase in pressure at a given speed may be just sufficient to prevent the loss of contact between the brush and the commutator, therefore we get continuous friction instead of intermittent friction. One difficulty I have is in understanding the nature of the contact drop to which the author calls attention. He regards part of it as still remaining when the voltage is reduced to a point below which no current will pass. I have found in some experiments with ordinary carbon brushes, making contact with a stationary copper plate, that current will pass at any voltage so long as that voltage is high enough to overcome the very slight thermo-electric effect due to contact between the brush and the commutator. That does not seem to explain, however, all the figures that the author gives, and I should like to have some further information on that point. One would think that a brush which is actually making contact with a metal surface must always pass current when there is any potential difference at all. It would be very interesting to take some oscillograph records between the brush and the commutator at various speeds. It would tell us very much more clearly what is actually happening whilst the collection of the current is going on. The author has referred to a suction effect between the brush and the commutator. I quite believe there may be such an effect very similar to that between very highly finished metal surfaces. If the surfaces are sufficiently highly finished, no air can enter between them if they are pressed together. It is quite possible that when a brush gets thoroughly well bedded down on to the commutator this effect is obtained, and at the extreme limit we might get a pressure of 15 lb. per square inch tending to prevent loss of contact between the brush and the commutator. With regard to the question of size, large brushes are necessarily used for large currents, but they are unsatisfactory. It is practically impossible to get a very large brush bedded down well on to the commutator, and on the other hand if we multiply the number of parts we get trouble with complication. It seems to me it would be advisable to make experiments with divided brushes for large currents, the divisions being made circumferentially. Each brush would be smaller and lighter, each would have its own tail and slide, and we might in that way get very much better results. As is well known, Professor Miles Walker uses a split brush on some of his machines, but for a different purpose. One point about the use of carbon brushes is the margin they allow for inexactitude of calculation and imperfection of material. One does get a very big margin to work on by using different grades of brush, but that unfortunately means one has to have many qualities. One can standardize sizes fairly well, and our President has done a very great deal in that respect. In the Navy we do not use very many sizes of brushes, but unfortunately we have to use several qualities. I suggest that it might be an advantage to make a greater distinction between the different qualities of brushes to avoid the danger of taking a wrong quality of brush from stock and mixing it with brushes that are not of the same quality. That leads to hopeless results. I therefore suggest that the ends of the brushes might be marked with grooves formed in moulding them. One kind of brush might have a plain top, another with grooves made parallel to the sides, and another again with diagonal grooves, so that the brushes could be easily distinguished and mistakes avoided. Such simple markings used alone and in combination would serve to distinguish six qualities. The author has referred to the question of recessing the mica in the commutator. I thought we had almost got to the position where it was accepted as necessary to recess the mica on all commutators, but recently we have found it very desirable in some large motors in the Navy to go back to smooth mica because of the trouble experienced with oil and dirt collecting in the grooves. I think that the commutators if they had been in a clean situation would have run better with recessed mica, but difficulty was certainly caused by the grooves in this case. With any commutator, success is only obtainable if the air surrounding it is free from dust, dirt, and oil. If more attention were paid to this point, better results would be obtained with many machines which now give trouble. There is one little point I should like to mention with regard to the bedding down of the brushes. The ordinary method is to take a strip of carborundum cloth and pull it to and fro under the brush. One gets a curve approximating to the commutator curve, but it is obvious that that curve is not correct since it has a radius equal to the commutator radius plus the thickness of the cloth. It is necessary to run on an average for two or three hours before the brushes come into proper contact with the commutator. The question of copper "pick-

ing" is rather difficult. I do not think we ought to call the action electrolytic, because, if so, where is the electrolyte? It seems to me it is purely the carrying over of particles of copper from the commutator by the minute sparks formed when the brush jumps from the commutator. This appears to explain its occurrence only under the negative brushes. It always seems to me a pity to use carbon brushes with a plain collector ring, but at the same time one does get fairly good results, and one probably would not get such good results easily by using metal brushes without lubrication. If too little surface is used, with high pressure as in a controller, efficient lubrication is impossible and the wear becomes excessive. If we lubricate the brush properly, the brush is separated by the lubricant from the surface from which the current is collected, and that defeats the end in view unless the lubricant is conductive. It seems to me wrong to use a high-resistance brush with a plain ring, except when unavoidable. There are four main points to observe in the design of brush-gear. First, we must have as nearly as possible a mathematically true collecting surface when running; secondly, all the brushes and parts attached to them that move must be light; thirdly, good lubrication must be provided, so that, fourthly, as heavy pressure as possible may be used in order to prevent the tendency of the brush to jump from the commutator. The more closely each of these points is met the better will be the results obtained.

**Professor J. T. MacGregor-Morris:** The paper gives us a number of facts connected with carbon brushes on which I think we can rely to a large extent. There are certain points upon which I should like the author to give more information, the first being with regard to the contact drop, a matter to which Mr. Constable has already alluded. How has the contact drop been measured? Has it been measured by an ammeter and a voltmeter, putting the ammeter in series and the voltmeter in parallel? The next point I wish to refer to is testing. The author refers in a general way to the contact drop of collector rings. I should like to know whether the curve in Fig. 1 is determined for a collector ring or for a commutator having no armature attached to it, or for a commutator with an armature but with the field winding not excited, or for a complete machine which is working under load. I believe that the results obtained in each case would be different. Mr. Constable has already alluded to the question of the contact not carrying current below a critical value. I do not know how low that value is, but I have measured contact drops on machines with commutators in as perfect a condition as possible, with the brushes very carefully bedded, and I have been unable to detect a point at which no current will pass. When the author speaks of sparkless commutation or no visible sparking, does he imply that there is absolutely no sparking at all underneath the brush when it is running? If that is so, then the theory may be different from that in connection with the potential difference across an arc. I should like to illustrate some comparative results obtained for the contact drop on a 2-kw. machine. The machine was driven by a separate motor, its fields were not excited, and a current was sent through the armature from a separate source, and the voltage across the machine and the current flowing were measured (see Fig. A). The curve is very much like the author's curve, but my experiments showed that beyond the curved piece, the curve becomes straight. It is true that the current density did not exceed about 12 amperes per square inch, and I believe that when we get to much higher values another effect is introduced, a grosser kind of sparking, which suggests a possible reason for this curve turning off as shown in the paper. If we take a microphone, which has a large number of contacts

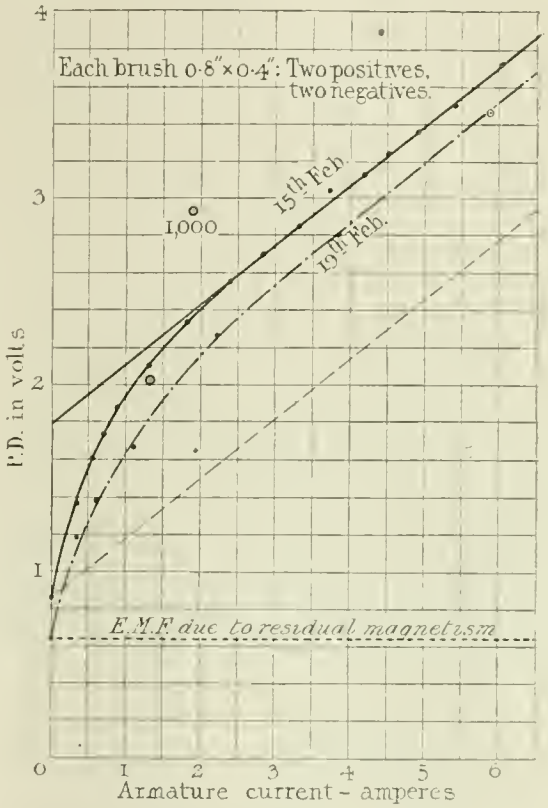


FIG. A.

Speed constant of 110-volt motor at 500 r.p.m.
Only residual field acting; no current in shunt winding.
Driven by another motor, various currents were passed through the armature and the drop at the brushes was measured.

in parallel as well as in series, the volt-ampere curve would be like Fig. B, which resembles the previous curve. I suggest that the theory underlying the microphone contact may be the same as that which underlies the single contact used in the motor. There is perhaps another method of measuring the contact drop. I have suggested that if it be measured when the machine is working on full load, it would be different from the contact drop at no load. [**The Author:** My curve was taken on a short-circuited commutator.] For practical work one wants to know the contact drop when the machine is on load, and that is much more difficult to obtain. I have attempted to obtain it in the way shown in Fig. C, but have so far failed. Three machines like an ordinary booster set are used. Two

of the machines are identical, and the other is a small booster. Those two machines were for 240 volts and were connected as in the Hopkinson test, whilst the small machine kept the set running, so that it supplied the friction, windage, hysteresis, and eddy-current losses. The voltmeter reading gives correctly the

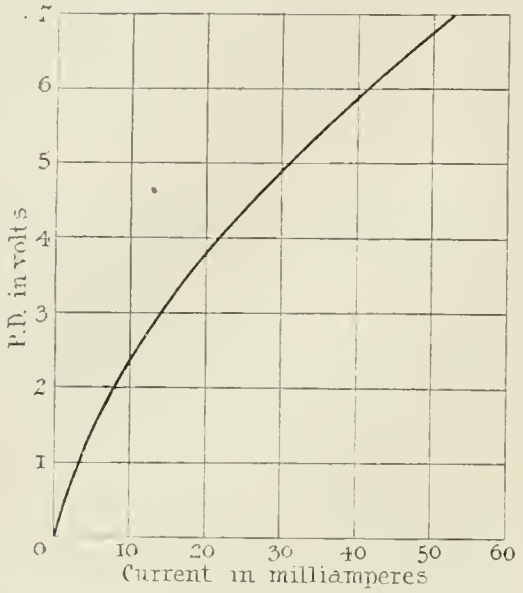


FIG. B.—Volt-ampere characteristic for a standard form of microphone.

contact drop at very small loads when the armature copper drops have been deducted. But unfortunately on load one machine works as a motor and the other as a dynamo, so that one field is distorted forwards and the other backwards when loaded, and a back electromotive force is therefore introduced into the

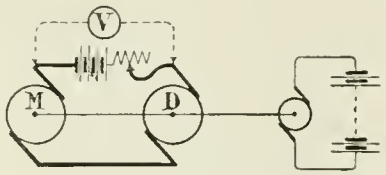


FIG. C.—Diagram of connections.

circuit, which upsets the measurement. In order to correct for that we should have to shift one pair of brushes backwards and the other forwards, or determine experimentally the magnitude of this correction. I do not know whether anything practical can be made of this suggestion, but I do feel that it is important to obtain measurements with the machine on load.

**Mr. R. Orsettich**: I should like first of all to refer to the universal brush which the author appears to have dismissed as an impossibility. I would point out that when dealing with this problem we have to consider different classes of machines. Large generators are always ordered and kept supplied with a reasonable amount of spares, and these are available in the correct quality and quantity when required. The same remark applies to large users of motors, who can afford to keep an engineering staff to look after them. The user of small motors, however, who owns only one or two machines, generally has no spares. Whenever his brushes are worn out, this is usually indicated by excessive sparking, and he has to obtain a set of brushes from stock from an ordinary dealer. It is absolutely impossible for such dealers to have available all qualities and makes of brushes, and usually the nearest best brush is taken and the motor run with it. It seems to me, therefore, it is essential that in making these machines and selecting the brushes, we should take care of that fact. I believe a universal brush has been produced by the firm with which the author is connected, and I believe it has proved very satisfactory indeed for average conditions. I can say from experience ranging over six or seven years that this brush has proved perfectly satisfactory for machines of between 300 and 460 volts. It is not a purely graphitic one; it has a fair amount of abrasiveness, and on the whole it works exceedingly well on ordinary motors. It seems to me that, if this brush could be further developed, we should not be so far from the condition which the author seems to think is very far ahead. Dealing with the question of leads and connections, it seems to me one point should be mentioned, viz. that the leads should always be twisted and not braided. I have had a great deal of trouble with braided leads in the past, and I now always specify only twisted leads. I believe the majority of engineers are adopting the same view, because twisted leads, when they do heat, can be untwisted and a larger cooling area provided with practically no other alteration. The question of the connections has already been raised. There are some brushes which have the flexible lead fixed by means of a short tube, riveted at both ends of a hole drilled through the body of the carbon. I have recently had to replace a large number of brushes made in this way which, for some non-apparent reason, broke right across. I explained the trouble through difference in expansion of the carbon brush itself and the copper or metal tube which was used for making the connection. In regard to the operating conditions of brushes, I missed from the paper a discussion of the oscillating gear as supplied to slip-rings and commutators of rotary converters. This is often specified, although there is no clear reason why it should be used on these machines more than on others where similar conditions obtain. Probably this is due to a kind of fashion, which started originally from the necessity of assisting the brushes in cleaning the surface of the commutator or rings, some artificial glutinous substance being applied to help in the lubrication. As machines are made to-day there should be no reason to provide such gear, which, without doing any good, causes the serious trouble of producing a convex surface on the brush and a concave path on the rings or commutator. The best way in which one could comply with the condition, if it be specified, would be by making the travel of the commutator as small as possible. Another point which has not been raised in the paper, is the artificial lubrication of rings. For some reason, makers of brushes appear not to have

been able to produce a brush which is sufficiently metallic to collect current at very high current densities and at the same time sufficiently self-lubricating to reduce the wear on the slip-rings, and the habit has been introduced of using brushes which have a very high co-efficient of friction and adding a wooden brush, or one made of some other fibrous material, dipping in a container filled with oil. This has been recently adopted in several stations, and it seems to me to be desirable that makers of brushes should eliminate such a makeshift arrangement and produce a brush which is sufficiently self-lubricating to avoid the necessity of artificial lubrication. Another point I should like to mention is the use of a curve indicating the voltage drop across the brush to show the distribution of current in the contact surface. This curve is nowadays practically standardized by all makers, and it is the only criterion we have for the purpose of adjusting the strength of the commutating poles, unless one should test the machine at full load. In view of the importance of this curve and of the information which it gives, I think it should be considered and criticized further. I should also like to know if the author has endeavoured to determine the maximum voltage which can be short-circuited under the very worst conditions between the extreme tips of the brush (this is the "apparent" short-circuit E.M.F. of the brush). Mr. Lamme read a paper at San Francisco some three or four years ago in which he discussed this matter at some considerable length. He then stated that under the very worst conditions he would never consider a higher pressure than 30 volts between the tips of the brush. I believe that most of the designers in this country were astounded by that figure, and that most brush manufacturers would also object very much to guarantee a brush which would work under such conditions, especially as Mr. Lamme showed in that paper that the adjustment of the commutating poles must be improved at the same rate as the voltage is increased, so that a brush which has 30 volts across it must have commutating poles adjusted within 90 per cent of the correct value when working under the conditions represented by this voltage. In connection with the standardizing of new brushes, the fact that the Electric Power Club has contemplated as many as 250 different sizes seems to me worthy of consideration. The point which must not be lost sight of is that there will always be a very large number of old-type brushes required as spares for machines now running, and that a good many of the sizes of these brushes could be retained for new standards. The standardization will have already achieved a great deal if we should not require to increase the number of brushes for the future. We must not, however, make the new standards too few or with too great gaps amongst them, to avoid either handicapping progress in machine design or compelling makers to go outside the standards for new designs. Further, standards should not be concerned with the quality of the carbons, but only with their dimensions; they also should not consider anything but the simplest forms of connectors and their fixing, and should always keep in view the possibility of having to shorten or narrow the body of a brush in order to adapt it for some other dimensions for which no other brushes are available. For this reason, copper covering of brushes should not be admitted as a standard feature. As approximate standard sizes I should like to suggest the following:—

(1) Length: 1 in., $1\frac{1}{4}$ in., $1\frac{1}{2}$ in.
(2) Thickness: $\frac{1}{4}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in., $\frac{5}{8}$ in., $\frac{3}{4}$ in., $\frac{7}{8}$ in., and 1 in.
(3) Width: $\frac{5}{8}$ in., $\frac{3}{4}$ in., $\frac{7}{8}$ in. 1 in., $1\frac{1}{8}$ in., $1\frac{1}{4}$ in., and $1\frac{1}{2}$ in.

These, after eliminating some combinations which do not answer practical cases, would give about 120 sizes and should fill most requirements, even for special machines.

**Mr. J. McI. Cater**: There is one thing I should like to say with regard to standardization. I have examined the lists of brushes which many well-known machine manufacturers require my firm to hold in stock for them, and I find that the number in one of them is 76, in another 53, and in a third 42, whilst the average of a considerable number of lists is something like 30. Standardization, therefore, it seems to me must first come from the machine builders and then the brush makers will be only too pleased to follow suit. One speaker has referred to the use of what he describes as practically a universal brush. I am pleased to think he has found something which so nearly approaches his ideal, but I venture to think as the representative of a concern in rivalry with that to which the author of the paper belongs that there will still be room for both of us in the manufacture of brushes for a very long time to come.

(*Communicated*): Abrasion is very frequently referred to in the paper, but in the experience of my firm it is quite exceptional for constructors using mica with a normal degree of hardness to specify that the brushes they require should have special abrasive qualities. It seems necessary, on the contrary, to emphasize the fact that an average high-grade carbon brush with or without graphite (excluding soft graphite brushes used on high-speed machines) will operate perfectly satisfactorily for years on machines with flush mica without any appearance of mica trouble, and this is well known to British constructors of electrical machines, as the result of their experience extending over 20 to 25 years. Innumerable instances could be cited of brushes containing no abrasive material producing splendid commutators without mica trouble and with a wear of the commutators so small after years as scarcely to be measured. It is almost a truism to say that a brush maker must never think of abrasives and that his products must be such as to be essentially non-abrasive. Some people have the mistaken idea that abrasive brushes are the best remedy for the prevention of blackening. Blackening is the result of unsatisfactory commutation, and may sometimes be cured by a non-abrasive brush having a higher contact resistance. As stated above, it is quite exceptional for inquiry to be made for brushes with special cleaning properties either with or without graphite, and such few cases as occur certainly do not exceed, say, 5 per

cent. These relate for the most part to brushes required for train-lighting dynamos, regenerative control, or similar purposes. I do not, of course, deny that for any particular machine suffering from proud mica the application of abrasive brushes is at times a remedy, but the case is an isolated one. On page 202, col. 2, the author says: "When the mica is well recessed a high-grade non-abrasive graphitic brush may be used, and the wear of both commutator and brush is reduced to a minimum." I do not agree with this statement. On the contrary, I maintain that experience shows that in most cases soft brushes are detrimental to commutators. Their use may result in a machine being enabled to operate satisfactorily, which is the main consideration, but this is at the expense of the commutator, and the latter frequently assumes a wavy appearance. I am obliged in fact to confess as a brush manufacturer that although in the case of high-speed machines with recessed mica soft graphite brushes supposed to be essentially non-abrasive and containing in fact no kind of grinding or polishing element in their composition should operate without commutator wear, the general rule is that the wear is incomparably more accentuated than with hard or medium hard brushes. This wear is so considerable that to prevent grooves and waves oscillators are frequently provided. On the other hand, when electro-graphitic brushes are substituted for the soft graphitic ones oscillators are unnecessary. To what is this wear due? The phenomenon is difficult to explain, but is possibly due to ionization occurring as the result of eddy currents under brushes which make very intimate contact with the commutator and follow it more closely than would be the case with harder brushes bearing on relatively fewer points of the collector. That the phenomenon may be of a purely mechanical nature is very difficult to say. As regards slip-rings, what I have just mentioned also applies, the wear with pure graphitic brushes being far greater than with the electro-graphitic. I believe that most textbooks and previous literature on this subject refer to the + or positive brush in the dynamo sense, i.e. collector to carbon, and the other brush as the negative one. This may be mere convention, but as the author uses the term positive brush in the motor sense it may be a point worth mentioning. One speaker in the discussion raised the question whether the curve in Fig. 1 should pass through zero. A test made in our laboratory has shown that it does so. The high thermal conductivity of a graphite brush does not satisfactorily explain why the flexible conductors on graphite brushes are liable to burn out, and I should like to add a few words on this subject. As has been stated in the paper, soft graphite brushes have a contact drop which is practically constant over a certain range of current, even with heavy loads. Now on a perfectly good commutating machine it may be admitted that, owing to some very subtle causes, an unequal distribution of current takes place. This, when started, rapidly accentuates itself, as the heating of the brushes which suddenly happen to be more heavily loaded than the others reduces their specific contact resistance and aggravates the instability under these conditions to such an extent that it gets out of control, and one particular brush probably grabs some hundreds of amperes, causing the flexible to fuse although the brush does not glow. The remedy for this trouble should be sought in the selection of brushes whose contact drop is not too greatly influenced by temperature rise. It may be of interest to mention here that, as a rule, brushes taking current from the collector show with a rising temperature a considerably smaller decrease in their contact resistance than those giving current to the collector, the figures being about 25 per cent from 30° to 60° C. in the former case, and about 50 to 60 per cent from 30° to 60° C. in the latter. This explains why, in unfavourable cases, with heavy loads and heating of commutator the negative brushes of a generator are the first to spark. Before leaving this subject, I should like to say that I believe a reason for the grabbing of heavy currents by soft brushes without glowing may be found not only in the high thermal conductivity but also in the softness itself, combined with the innumerable points in contact with the commutator. On the question of size of brush, much more might be said. To a very great extent the limit of size is controlled by the current to be carried, and relatively more current can be carried by a small brush than by a large one. Observations have been taken on a very large number of machines and the results plotted for the purpose of showing the proportional decrease of admissible current densities. The following table shows the kind of results obtained:—

| Grade | Permissible Current per Brush having a Contact Area of | | |
|---|---|---|---|
| | ½ sq. in. | 1 sq. in. | 2 sq. in. |
| Carbon .. .. | 16 | 26 | 47 |
| Electro-graphitic .. | 24 | 42 | 68 |
| " " | 33 | 54 | 83 |
| Graphitic .. .. | 36 | 58 | 92 |
| Copper-graphite .. | 47 | 90 | 140 |
| Bronze-graphite .. | 67 | 130 | 210 |

This table shows that if on an alternating-current machine with 10 copper-graphite brushes on each ring, each brush having a contact area of 1 square inch and a load of 90 amperes per square inch, one brush were for any reason to stick in the holder, the remaining nine would be overloaded by 11 per cent, whereas if the number were increased to 20, and the contact area of each halved, the overloading would be diminished to about 4 per cent. This, of course, is an exaggerated case, but serves to illustrate my point, which I venture to think is of considerable importance in view of the very large slip-ring brushes that have been fitted by some constructors during the last year or two. I should like to suggest that the maximum current per brush should be standardized, and for the sake of discussion I propose, say, 60 to 70 amperes per brush for direct-current and 100 or 125 amperes per brush

for alternating-current machines. When brushes are to have fittings added, it is distinctly advisable that the carbons should be coppered. The reduction in the resistance between a brush and its fitting is in the ratio of 10 to 1 for coppered and uncoppered brushes respectively, and this fact alone shows the advisability of coppering carbons under the fittings. The spring pressure on a brush should be reduced to a minimum, and it is probable that even in exceptional cases the 6 lb. per square inch mentioned by the author for traction brushes is excessive. American experience shows that on good commutating traction motors a light spring pressure, particularly with electro-graphitic brushes, is most desirable. It should undoubtedly be the aim of every engineer so to maintain his gear as to avoid excessive spring pressure. The author mentions that Admiralty gunmetal (88 per cent copper, 2 per cent zinc, 10 per cent tin) has been found excellent. Another mixture for slip-rings which has given very satisfactory results contains 90 per cent copper, 8 per cent tin, 2 per cent phosphuret of copper. It seems difficult to admit the possibility of electrolytic action in the case of a.c. slip-rings on account of the continuous change in the direction of the current. Copper picking usually occurs when working conditions are unfavourable, and particularly when heavy currents have to be dealt with. Heating then takes place, and as the contact between the brush and the collector may be described as being made at a large number of points, copper is deposited round that zone where the contact is most intimate; dust is next caused by the brush eating into the ring, and an accumulation of copper results. The same difficulty may also occur with copper and graphite brushes when very heavily loaded, the sequence being (1) heat, (2) volatilization of copper, and (3) quick wear of the roughened surface. The author states that when a few graphitic brushes are mounted on the same slip-ring with metallic brushes, the former having a contact drop so much higher than that of the latter will carry no current whatever, and that incidentally there is no need to fit them with flexibles. I do not agree. Measurements just made to determine this point have shown that on a 1,500 kw. rotary converter fitted with a mixture of bronze-graphite and graphitic brushes the former carried 125 and the latter from 4 to 5 amperes per brush. The author's statement would only be correct if there were a minimum contact drop below which no current would pass; but as this is not the case, all contact curves passing through zero, the graphite brushes necessarily follow the law $I=E/R$ (E being the volts between the ring and stud and R the total of the resistances, including the contact resistance). It is probable that the ionization of plumbago is a material aid to the lubrication of the ring, and that even if the current be so small as 1 ampere it has a beneficial effect. In these circumstances it is manifestly advisable to assist the lubricating effect as far as possible by fitting the graphite brushes with flexibles.

**Mr. H. Brazil**: The cutting away of the mica between commutator segments is now recognized to be the best practice in almost every case, but it is very necessary to be careful not to cut too deep. In a case I had under observation, where a dynamo was directly coupled to a Diesel engine, the vaporized fuel-oil deposited between the segments became carbonized, causing arcing between segments, and this arcing burnt away the mica to a considerable depth, necessitating re-making of the commutator. I was very interested to hear what the author had to say about the partial vacuum formed between the brush and commutator increasing the coefficient of friction, and while quite agreeing that tests taken in the laboratory would be of value, I think that one cannot apply any quantitative measurements obtained there to actual practice where it is impossible to eliminate dust. A point that interests me very much is the addition of a small quantity of abrasive material to the brush, and the effect this has upon the running of the machine. We had a rotary converter, the commutator of which was working at 4,700 ft. per minute peripheral speed, and the brushes at 33 amperes per square inch. The brushes contained a certain quantity of abrasive material, and the machine ran very satisfactorily, except that the amount of copper dust due to the abrasive action was rather larger than was expected. To get over this, a set of brushes having, I believe, about 4 per cent less abrasive material in them was tried. The commutator was ground up perfectly true to start with, but after eight days the brushes were sparking so badly that the machine had to be shut down. The commutator was re-ground and another trial was made, with precisely the same bad result. The commutator was ground once more and the old brushes put back, with the result that except for the amount of copper dust, the machine has run quite satisfactorily ever since. This case emphasizes the importance of small details and of keeping the commutator clean by adding a suitable amount of abrasive material to the brush. With regard to brush holders, the sliding type with flexibles embedded directly in the brush appears to be recognized as the best practice, and I am glad the author emphasizes the importance of making the brush holders very solid. I had some experience of a rotary converter with brush holders made up of sheet brass, with springs pressing the brush against the side of the box. Various springs were tried and adjustments made, but the running was very unsatisfactory due to the tendency of the brush, after running for some time and forming a good surface, to get tilted and start forming an entirely different bevel. These brush holders were replaced by the solid cast type with a very small clearance between the brush and box, and this type has proved to be excellent. On the question of flexibles, I think that as large a section as possible should be provided, having due regard to the free movement of the brush in its holder, and to obtain this result it is better to use four small flexibles than two large ones. An arrangement I have used and found very satisfactory, as it does away with all sweating of thimbles, is to fix two flexibles so that they come out at one end of the brush and re-enter at the other, thus forming a loop. The centre of the loop is twisted round the screw in the brush holder, and the whole arrangement is the equivalent of four flexibles with thimbles on each. With regard to slip-rings, it seems impossible owing to the

presence of dust, and to the slight variations of hardness in the brush and the ring, entirely to prevent grooving, but as long as the groove and the brush fit one another no appreciable heating results. The obvious cure for this is the armature end-play arrangement mentioned by Mr. Orsettich; but I am entirely in agreement with him that it is not satisfactory. We have tried it and given it up, as it introduces trouble on the commutator end.

**Mr. H. F. Joel, jun.**: Some years ago I attempted to prepare a paper on this subject. I had through my hands something like 100 different kinds of brushes and 30 different kinds of mica, but I had to stop, owing to the war. I find, however, that the majority of my data is confirmed by the present paper. One of the great difficulties I found was that the mica varied so much in hardness, that with abrasive material in the carbon it was impossible to keep the mica in its place. By cutting the mica into the sizes required, separating them with little sheets of nickel, bolting several complete sets between iron plates and making them red hot, I found that even a soft brush would keep the mica in its place. The mica under these conditions was not injured from an insulation point of view. This is good practice with pure mica, when we can see what grade we are using, but with built-up mica, when any old scrap can be and is used, it is of the utmost importance if we wish to avoid flats and trouble. The cement should have a very low carbon factor and probably gum tragacanth and water is useful. I suggested to a carbon maker that he might make some brushes in which the abrasive material was mica, which I find is perfectly satisfactory and cuts away the mica in the commutator without touching the copper. There is no difficulty in designing a machine to suit any carbons, and at most three grades should cover all requirements. (1) "S" type, "Le Carbone" with mica abrasive for high-voltage machines. (2) Electro-graphitic with mica abrasive for low-voltage machines. (3) Electro-graphitic with copper for slip-rings. Unfortunately, many machines are designed and the brushes are experimentally fitted on the test bed. The commutator is skimped in axial length, and to keep the current density of carbon within reasonable limits makers have to use a wide (circumferential) brush. This gives rise to large circulating currents within the brush, great heat, and a multitude of quantities of carbons, which is not conductive to intensive production or economy. I agree with Mr. Orsettich that all small motors up to 10 kw. should be run with any brush. As a maker of small machines I find that when the machines are sold the customer seldom asks the maker for a brush, but goes to the nearest brush factor, and it is essential that they should run well with any ordinary brush. The under-cutting of commutators is an evil to overcome, an evil caused by the hard mica. If one can keep the mica in its place, undercutting is quite unnecessary. My experience with slip-rings is that in the majority of cases the brushes used are copper carbon, and the rings are copper. I suggest that if copper rings are used, we should use iron in the brushes, or, better still, cast malleable iron or steel rings and copper-carbon collectors, as copper or brass slip-rings are only a conservative convention and unnecessary, and it is well known that dissimilar metals work better together as bearings than similar metals.

**Mr. P. R. Friedlaender**: I wish to refer to the difference that the author mentioned between negative and positive brushes. I recently made some experiments on some very small series motors, running at about 10,000 to 15,000 r.p.m., which were normally quite sparkless, but whenever the mechanical balance of the armature was faulty these machines showed a very peculiar sparking effect, the sparking being practically confined to the negative brush. There is only a single brush on each side, so that mechanical vibration at these very high speeds is liable to break the circuit by throwing the brush right off. The sparking is quite characteristic. The positive brushes show a slight red sparking, whilst the negative brushes show a long blue spark, perhaps $\frac{1}{4}$ inch long, drawn out round the commutator in the direction of rotation. If the polarity of the supply is reversed the sparking is transferred from one brush to the other. The effect seems to be due to some commutator copper being vaporized where the current passes from copper to carbon through a bad contact. It is also clear that the current is intermittent, from the fact that an appreciable shock can be felt across the field winding, although the normal drop there is only 3 or 4 volts. This is purely a mechanical effect, because the same machine with a copper-leaf brush or with greatly increased brush pressure will not spark at all. It is a question of arranging a brush so that only one part lifts at a time. Neither of those remedies, however, is satisfactory, because of increased wear. The mechanical balance must be put right. Very many of the troubles mentioned by the author would be got over by something like a flexible carbon brush. It is not a practical proposition at present, but I have made experiments—and I expect that many other people have done the same—with the object of getting something which will have the qualities of a carbon brush as regards conductivity and contact resistance, but otherwise resembling a piece of asbestos. It is not obtainable at present, I know, but over 30 years ago Mr. F. H. Varley took out a patent for a flexible carbon for use on an arc lamp. I have tried material made to that specification, but it is not workable as a brush, as it is not tough enough. It seems to me, however, that it is not an impossible proposition. Such a brush would resemble a copper gauze brush, in being able to raise itself in parts without leaving the commutator completely, in spite of a certain unavoidable amount of mechanical irregularity.

**Mr. H. K. Whitehorn**: Since carbon brushes are used far more on commutators than on slip-rings, if the results given were more directly applicable to commutators than to slip-rings they would have been more valuable, but it is difficult to get reliable results of contact drop from anything but slip-rings. The difficulties of making measurements on a commutator, particularly with the field excited, are due to the circulating currents in the short-circuited coil, which interfere with the results obtained. There are four

important points in relation to the use of brushes on commutating machines: (1) grade; (2) spacing, which is overlooked in the paper, although the author mentions some mechanical points; (3) the fit of the carbons in the holders; (4) bedding. It is impossible to exaggerate the importance of making the mechanical conditions as perfect as possible. I am convinced that a great many troubles that are now thought to be due to the carbon will be found to be due to incorrect spacing of the carbons round the commutator. A good plan is to wrap paper tightly round the commutator, and then cut a mark on it with a flat blade pressed against the side of the holder. The measured distance between the marks must be adjusted to be equal within $\frac{1}{2}$ per cent. If lowering of micas be done at all, it ought to be done thoroughly to get success. Dealing with machines up to about 100 h.p., narrow brushes will be found, from several points of view, to give extremely good results. It is difficult in discussing a paper on carbon brushes to eliminate questions affecting the design of the machine. The following are figures of a 25-h.p., 4-pole, 110-volt, 1,000-r.p.m. machine, with a 9-in. diameter commutator. A soft graphitic brush (type B), four bars, three carbons per bar, 1 inch by 7/16 inch, giving a current density of 70 amperes per square inch (the makers recommend 60) gave in three hours an armature temperature rise of 50 degrees C. and a commutator rise of 89 degrees C. Using the same number of brushes, 1 inch × 5/16 inch, still called by the makers a soft graphitic brush (but type H.M. 6), gave a current density of 98 amperes per square inch, and after $5\frac{1}{2}$ hours the armature temperature-rise was only 35 degrees C. and the commutator rise 30 degrees C. with sparkless commutation. The micas were lowered in each case. It is an instance showing that brush selection is very important. The machine is on full load six days a week.

**Mr. A. B. Eason**: I want to ask two questions. If the curves which the author has given are plotted on log paper it will be found that the contact voltage-drop takes the form of a law:—

$$\text{Contact drop} = \text{Constant (Current density)}^n.$$

I worked out some of the figures and they show that no matter how far the density is reduced, current still flows, and that the figure 0·74 given by the author really does not exist. I should like to ask him if he could give the values of the constant and of $n$ as found from all the tests connecting contact drop with density. I next want to refer to undercutting the mica. The author suggests that it is useful when the commutator runs at high speeds. Would it be useful at low speeds? If not, where would he draw the line between high and low speeds; at 2,000 or 3,000 or 4,000 ft. per minute? Two papers dealing with brushes might be referred to. The *Revue Générale d'Electricité* (1918, vol. 4, p. 115) has a paper dealing with the standardization of carbon brushes in France. One standard adopted is of the type—objected to by one speaker—which has metal plates riveted to the brush. Martindale (*Proceedings of the American Institute of Electrical Engineers*, 1915, vol. 34, p. 973) deals with the general use of brushes on commutators in practice.

**Mr. Ll. B. Atkinson**: It is some years since I have had the opportunity of studying in any great detail the question of brushes; but in the earlier days of the dynamo, when sparking was a much more difficult question than it is now—at all events in smaller machines—it was a subject to which I gave a very great deal of attention. The first patent I ever took out was for a brush that prevented all sparking, and that brush had in it the principle that lies at the root of carbon brushes, namely, a transverse resistance, a resistance between the point and the heel. These brushes were made of copper layers with resistances between each layer, and enabled machines that ran very badly with certain currents to carry two or three times those currents, so far as sparking was concerned, without any difficulty. This type of brush was discussed before the Institution not very many years ago by Mr. Mordey, who gave some very interesting results of his own experiments on a similar type. Two things, however, happened. First of all, dynamos were very much improved, so that the question of commutation was less important. Then came the invention of the carbon brush, and from that time onwards we have moved forward. But still I feel that it is difficult to say whether the carbon brush has been more of a blessing or a curse to the industry. It tided us over a point so that we were able to do a great many things at a time when otherwise they could not have been done. That particularly relates to the tramway and the locomotive motor. It seems to me there are two ways in which we may look at the carbon brush. To begin with, everybody will admit that to try to collect current from a solid commutator by means of a solid brush, fitted as well as it may be, is mechanically and electrically the worst possible way of doing it if it can be done in any other way. But first in the case of small motors that will be in inexperienced hands and where the commutation is not difficult to deal with, it is a great convenience to have a brush that does not alter its shape. Once fixed in position it stays until it is worn out, but that does not necessarily involve a carbon brush at all—it might really be a solid metal brush. We naturally use carbon because it keeps its shape, but it is purely an alternative. Then we have the use of carbon brushes to adjust the commutation when we have not succeeded in producing a true electro-dynamic commutation. But what are we doing? We are at once lowering the efficiency of the machine. It would perhaps have sparked so badly that we could not use it, so we fit a carbon brush and the energy which was going before in the spark is now being wasted in the brush. That is where the carbon brush has been, I think, perhaps a curse to the industry, because it has enabled us to use machines of inefficient design which we should have corrected if it were not for the simplicity of this solution. The number of brushes that have to be made of different qualities shows the extent to which they are being used as correcting agents for really incorrect designs and incorrect constructions. The point at which the carbon brush became absolutely imperative in my own experience was when we came to the slotted armature. The old smooth-core armatures did not require carbon brushes,

and if we had those to-day I do not think we should need carbon brushes. I think the use of carbon brushes with slip-rings is really inexcusable, and I do not know why it should be done. I have never found anybody who could give me a proper reason for it beyond the fact that people like a brush which once inserted need not be taken out again. A previous speaker queried the use of flexible carbon for brushes. I have used brushes having metallic layers with Varley flexible carbon in between the layers as a resistance. Used in that way we are not employing carbon to collect the current, whilst as a resistance it is very effective. We can also make brushes with metallic resistances between the layers that collect the current very well and have a very considerable commutating effect. One item in the paper which interested me very much was the question of a fixed contact drop across the brush. The curve is fairly convincing, but on the other hand Professor MacGregor-Morris has shown us that certain other conditions arise. I think it is a question that we ought to settle, because if the author's statement is correct we have an element there that does not exist in the metallic brushes that I have been speaking of, and that is not ordinarily taken into account in the discussion of the carbon brush for a commutating purpose. I should like to hear a little more about that from the author in his reply to the discussion, and it may be that further research is necessary on the point.

**Mr. A. A. Pollock**: I should like to call attention to what I consider to be an incorrect statement in the first column of the paper, where the author, in speaking of commutating-pole machines, says that the commutating flux is correct for one value only. I maintain—and I think all other designers of electrical machinery will also maintain—that the flux is substantially proportional to the load up to the point where saturation begins, and that point on a properly designed machine should not occur until the maximum prolonged overload is reached, i.e. about 25 per cent overload. The general impression I received on reading the paper was that the author considered the designers of electrical machinery to be very haphazard people. I think the reason is that he had had to deal with such a large number of ancient machines, and that if he had had only up-to-date machines to deal with, fitted with commutating poles and properly adjusted, many of the remarks he has made would not apply. Speaking of my own experience of machines over, say, 100-kw. capacity, it is our practice so to adjust the strength of the commutating field that there is substantially a constant voltage drop across the brush from the heel to the tip, and this makes it possible to use a low-resistance high-grade good-lubricating brush. We use practically one class of brush on all machines of the larger sizes, and I think there are only one or two cases where we have had to change the brush in order to help commutation. There are cases where changes in brushes have been found desirable, but not necessary from the commutation standpoint. With respect to ring wear, the author gives on page 197 some data regarding the rate of wear of slip-rings with pure graphite non-abrasive carbon and abrasive carbon brushes, without any current flowing. It would be very interesting to know what rate of wear he has found with a copper graphite brush under similar conditions. It may be of interest to mention that we made a test, among very many others, with slip-ring brushes of one of the Morgan Crucible Company's grades. It was a copper graphite brush running at 100 amperes per square inch; peripheral speed 3,800 ft. per minute, and a pressure of 2 lb. per square inch. This brush was run for 44,000,000 revolutions and showed a radial wear of the ring of 0·052 inch for 20,000,000 revolutions, which is getting towards the figure given by the author for the abrasive carbon brush without current. In this case alternating current was flowing. With respect to the question of the varying contact resistance and varying friction coefficients observed at different peripheral speeds, I think the author's suggestion that an air film exists under the brush is the correct one. An extremely minute air film would not appreciably affect the contact, although it would certainly affect the contact drop. The question of the contact resistance dropping with increase in temperature might be explained by the rarefaction of the air due to heat expansion and the consequent squeezing out of the film a little more. I think it would be interesting if the author could conduct some tests *in vacuo* to settle definitely this point, because if he were sure of the ground on which this theory was based it would be very useful in designing certain classes of machines. With reference to the question of the wear of slip-ring machines, referred to on page 202, it would be very interesting if the author could give us the duration of the test on which these particular curves were plotted, and how it varies with graphite brushes, because I believe that with the latter very good results would be obtained. With respect to the sizes of brush, I should like to say that I am in thorough agreement as to very large brushes being unsatisfactory in service, but I think it is distinctly advisable to make the size as large as possible, consistent with satisfactory operation, because of the reduction effected in cost of brush renewals.

**Mr. R. S. Allen**: There are two points which stand out very clearly before me to-night. The first is the question of standardization of grade, and in this connection I agree with Mr. Orsettich that the number should be reduced as far as possible. The fact that he has found a series of machines to run satisfactorily with one grade of brush is evidence in this direction. Curiously he has adopted the "A" grade as a standard, whereas our experience has led us to adopt the "C" grade for most machines working at pressures from 100 to 600 volts. The second point which has not been touched upon is the advantage of low inertia of brush, especially in high-speed machinery. The continuous succession of "bumps" in commutators (the result of a cylinder built up of segments) have to be regarded, for if one has a brush which will immediately respond to those bumps, the result is less wear and general better behaviour of the commutator. I have in mind the case of a 4,000-ampere 100-volt generator which was originally fitted with "B" grade brushes, the characteristics of which are low coefficient

of friction and low contact drop; the temperature rise was, however, very considerable. On consulting the Morgan Crucible Company they produced a brush of considerably less inertia which allowed of a smaller tension on the main springs and so less friction, and at the same time the contact drop was not increased, so that the reduction in temperature which followed was very remarkable. To obtain full advantage of the low inertia, a spring leaf-metal top was fitted to the brush, which spring was so successful that we introduced its equivalent into one of our standard holders as a part of the pressure arm. By means of the subsidiary spring, a brush can associate itself much more closely with the commutator than when its movement is damped by the comparatively high inertia of the brush arm and main spring.

**Mr. G. Broughall** (*communicated*): I feel that there is still plenty of scope for investigation into the question of what actually takes place between the surface of the brush and the surface of the commutator or slip-ring, and that such investigation is a profitable one for further research. It has always seemed to me somewhat surprising that this question has not been more fully investigated hitherto, in view of the very important part which the characteristics of the carbon brush, particularly as regards contact drop and specific resistance, plays in the performance of commutating electrical machinery. The use of carbon in place of metal brushes has been of the greatest advantage to both the designers and the users of electrical machinery; indeed, if we except the commutating pole and compensating winding, this simple change in material has been perhaps the most important factor in the development of modern electrical machinery. In my opinion it is of great importance from the user's point of view to obtain the brush which is best suited to the commutation characteristics of the particular machines which he has in operation, and it is not always an easy matter to ascertain which is the proper brush to use. It would assist matters very much if the vendors or designers of the machines would, when selling the machine, inform the purchaser what particular characteristics the brushes should have in order to obtain the best results under normal working conditions. In my opinion it pays to buy the very best quality of brush obtainable. The curves given in the paper are very interesting and instructive, but there are so many grades containing different percentages of graphite and the method of making the brushes introduce other variable factors, so that one can only take the curves as typical and as indicating the manner in which one may expect the performance and losses to vary under different conditions of pressure, peripheral speed, and current density. I have experienced more difficulty in obtaining a brush that will work satisfactorily on the slip-rings of rotary converters than with the brushes on the commutators. There appears to be a marked tendency for the formation of flats on slip-rings, and, whilst several different kinds of brushes have been tried, the most promising arrangement appears to be to use a brush having a high metal content with a small amount of oil lubricant continuously applied to the ring. It is possible that this tendency to form flats may be occasioned by burning of the rings at the moment of cutting out the starting motor. For some time I was puzzled by the formation of flats on the steel slip-rings of turbo-alternators, and the author's remarks on page 200 indicating that this trouble is likely to be caused by oxidization of the rings where not covered by the brush when the machine is at rest may throw some light on the trouble. Under the heading "Contact Drop" on page 195 he points out that for each quality of brush there is a critical value below which no current at all will flow. This is a very interesting point and suggests to me that "contact drop" may consist of two components. The problem may have something in common with that of arc welding. In both cases we have two electrodes or surfaces with a current flowing between them, and if the surfaces are separated an arc will be formed or will tend to form. In the case of arc welding the electrodes are separated and a voltage is necessary to overcome the counter electromotive force of the arc, in addition to that required to drive the current against its ohmic resistance. In the case of the brush and slip-ring or commutator the surfaces are probably never actually separated unless the rotating surface be out of truth; nevertheless, it is probable that even in cases of so-called sparkless collection there is minute sparking taking place between the brush surface and the commutator corresponding to some extent to an arc or a number of small arcs in parallel and requiring an electromotive force to maintain it, apart from that to overcome ohmic resistance. Of course in this case the surfaces are moving relatively to one another and there is not time for actual melting or burning of the surfaces to take place unless the current be very excessive. The phenonemon of "copper picking" at the negative brush and the transfer of carbon to the commutator at the positive brush, mentioned on page 200 of the paper, would appear to indicate that some such action as I have described does take place. I must, however, point out that the curve given in Fig. 1 does not appear fully to bear out this theory, and I merely make the suggestion for what it is worth.

**Mr. G. W. Edward** (*communicated*): By far the greater proportion of so-called "brush troubles" that I have met with have been found to be due to the faulty holders, or pressure springs, and sometimes to pinched design of commutator or slip-rings, rather than to faulty brushes. With regard to brush-holders, I agree with the author that the boxes should be cast, but unfortunately this type is more expensive to manufacture than the type built up of stampings. The use of holders made up of stampings is a source of a lot of trouble. They are never very regular in dimensions, and are easily distorted, which leads to the wedging up of brushes, unless an excessive clearance between brush and box is allowed for, and this excessive clearance is to be avoided. The use of stamped holders, if not altogether avoidable, should be confined therefore to small machines. All holders should be provided with an adjustable pressure device. Fig. 5 illustrates very clearly the importance of maintaining equal

pressure on all the brushes mounted on a machine, and unless the holder is fitted with an adjustable pressure device, this is impossible. One still finds a number of important units, turbo-generators and rotary converters, fitted with holders which do not render possible the adjustment of spring pressure. I should like to know if the author's conclusions with regard to the best brush angle to be used are based on experiment. The true pressure of the brush on the commutator or collector is the resultant of the applied pressure, and the force due to friction acting in the direction of rotation. Theoretically, therefore, I should imagine that brushes set reaction, with an angle of rake so chosen that the resultant true pressure of the brush

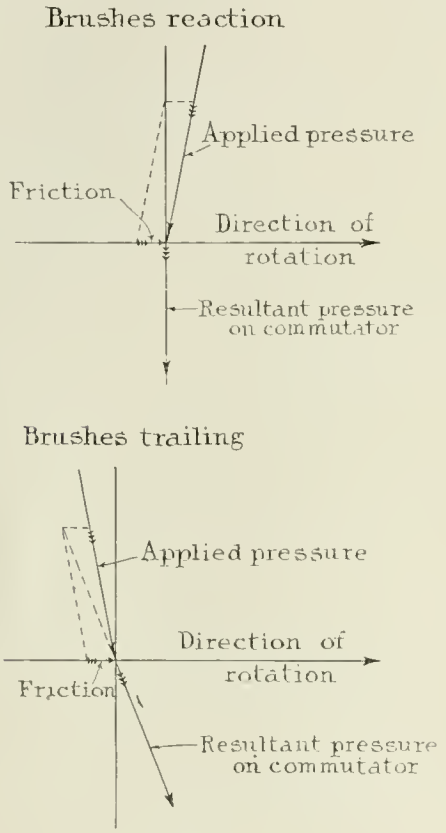


Fig. D.

on the collector is radial, should give the best results and lowest commutator losses. The angle of rake would vary for different qualities of brushes possessing different coefficients of friction, but a mean useful angle could probably be arrived at. With trailing brushes, or even with radial brushes, the resultant pressure on the commutator is not radial, and is greater for a given applied pressure than when the brushes are operated reaction. Further, this resultant pressure is at an angle such that it might lead to a wedging action between the tip of the brush and the holder (see Fig. D), greatly increasing the pressure on the commutator or collector, especially if there is any excessive clearance between box and brush. This increased pressure means increased friction loss. A test of friction losses on a machine taken with various angles of rake, reaction and trailing, might show some interesting results. I believe that reaction-type brushes are used very largely in the United States, and at least one important French machine constructor has adopted this type for large d.c. generators and rotary converters. This constructor makes his boxes with a particularly large clearance in the peripheral dimension (approximately 25 per cent of the brush thickness). The brush has two large bevels, at the contact surface and the top, and the pressure is applied on the top bevel. The angle of rake is approximately 27° to 30°. In practice, the brush only touches the front side (direction of rotation) of the holder. I have seen several large units giving complete satisfaction with this type of holder, which has the particular advantage, by reason of the great amount of clearance in the box, of rendering the sticking of brushes in the holder impossible. The electrolytic action that takes place between the brush and the collector, and vice versa, is very carefully explained in the paper and has been frequently noticed in practice, especially with alternator slip-rings. It is also borne out on d.c. commutators where the incorrect staggering is adopted, and where one frequently finds high tracks on the commutators although these tracks are covered by brushes. One still finds that many engineers are nervous as to recessing the mica, and in some cases, when they do so, fill in the slots with an insulating composition. This should not be necessary, and it would even lead to difficulties if the composition disintegrated. The usual contention of engineers who dislike recessing the mica is that there is considerable danger of dust collecting in the slots, and that they fear to decrease their brush wear by increasing their commutator wear. With regard to collection of dust, unless the machine is particularly slow running, and then the necessity of recessing the mica is not so manifest, and provided that lubricant is not used, there is little danger to be feared from dust, as this gets thrown out of the slots in running. With regard to the commutator, there is less danger of mechanical wear when using a graphitic brush on recessed mica than of electrical wear due to sparking caused by high mica. I have also come across machines the mica of which has been slotted, so as to leave a groove V-shaped in section, the idea being that even if a little dirt accumulates in the slots it is not likely to short-circuit the commutators bars. Great care must be taken with this method that the sharp ends of the mica V be not allowed to protrude, or the results would be disastrous to a soft graphitic brush. The curves shown in Fig. 8 illustrate the advantages that accrue to the machine and brushes if the current density is kept within reasonable limits, say 40 to 50 amperes per square inch. I should like to know whether the author can explain why the negative ring wear at 100 amperes per square inch is lower than at 60 amperes. Is it the result of an isolated test, or do conditions change materially with such a high current density? It would also be interesting to know whether there is anything to show that there is any difference in rate of wear of the brushes or rings in the case of alternating

currents of varying periodicities. With regard to brush standardization, it is interesting to remember that the Chambre Syndicale des Constructeurs de Gros Matériel Electrique of France, an association of manufacturers of large electrical machinery, have standardized the dimensions of brushes. They are divided into 4 classes, namely, 2 types of grip-type brushes with 18 and 30 sizes respectively, and 2 types of slide-type brushes, of which one type is rectangular with 21 sizes and the other a double-bevel reaction type with 4 sizes. Although the position of the flexible connections is fixed within certain limits, there are three possible lengths of flexibles to each of those 25 sizes of slide-type brushes, and no effort has been made to standardize either the terminals or the qualities of brushes. This standardization does not include brushes for traction motors.

**Mr. W. Guy-Pell** (*communicated*): A paper on this subject has long been wanted by those who have to attend to dynamos and motors. The author correctly states that the "brushes" are the weakest link in the chain, and from my experience, which has been long and varied, I am of opinion that they certainly require more attention than any other part. I believe that much of this trouble could be avoided if brushes and holders of a more suitable type were adopted by those responsible for the design of the machine, and much of the advice given by the author should be of material assistance in this respect. I venture, however, to criticize some of the points as to which I am not in accord with him, the first and most important being the mechanical form of the brush and the method of conducting the current from it to the terminal of the machine. For the latter purpose he recommends the use of flexibles, or, as some of us term it, "pigtail connections"; and he recommends a rectangular shape of brush not exceeding $1\frac{1}{4}$ inches × 1 inch for ordinary motors. Now on page 199 the author says that one of the characteristics required in brushes is "low inertia." I am not sure that this is not the most important characteristic; it is certainly not attained by adding to the carbon, which has a low specific gravity, copper and clamping terminals of high specific gravity. Moreover, on page 198 the author says that flexibles tend to make the brush sluggish. There are other disadvantages in the use of flexibles, but while speaking of inertia I would suggest that for ordinary work the dimensions generally adopted should be even more limited than those stated by the author. The peripheral width, of course, depends much upon the design of the commutator, but the axial width might well be at least 25 per cent less than the author gives. In place of the flexibles, I suggest the use of spring-controlled levers made of aluminium, to be as light as possible, the brush to be clamped between the end of the lever and face of the commutator and guided in a plain box without openings or detents at the sides. The contact between the brush and the end of the lever might be improved by the use of an aluminium washer the full size of the brush. There is no difficulty in any case in establishing a contact at this point, where the surfaces are stationary, that is at least equal to the contact between the brush and the moving commutator. The current should be taken from the lever to the terminal by means of a flexible attached at or near the pivotal part where there is little or no movement. Apart from the question of inertia, the use of flexibles is generally costly in renewals; in many cases they more than double the price of the brush. Moreover, the methods of attaching them to the brush are as numerous as the number of manufacturers of motors, so that it is necessary to have in stock practically as many sets of brushes as there are different motors in use, whereas by using plain brushes much of their duplication would be avoided. Certainly the orders for replenishing would be much simplified; at present, sketches or samples must accompany every order, and it must be remembered that the order has to pass through a multiplication of hands before it finally reaches the workman that is to manufacture. Many users obtain tenders before ordering, in which case sketches or samples have to be sent to each of the firms tendering. Another objection to this use of flexibles referred to by the author on page 194, is their liability to break under continual vibration. This, of course, is a more potent characteristic in high-speed than in low-speed machines: it is there, nevertheless. On page 195 the author states that the decrease in the coefficient of friction that is observed at high speeds is due to a film of air. I am not clear as to what he quite means by this. I gather he attributes the film to some action of windage or suction. I suggest, however, that it is due to the simple fact that the brush is not continually in contact, and that the coefficient of friction is reduced in proportion to the amount of vibration or separation, that is to say, to the fraction of the periphery upon which the brush is touching during each revolution. In fact, further on (see page 203) the author admits that commutators are never mathematically circular and a very small mechanical defect is sufficient to cause a momentary separation between the brush and the collector. Nor do I agree with what the author describes as suction or vacuum between the brush and commutator of low-speed machines, for it appears to me that the tendency to adhere is due to perfection of contact, combined as it may be in some cases with the presence of lubricating or plastic matter. In other words, the effect is due not to a space between the brush and the commutator in which there is a vacuum, but to the entire absence of space. I agree with the author as to the importance of having equality of pressure as well as correctness thereof. It would be interesting if he would supplement the paper by a description of the sort of instrument or apparatus that he uses for measuring this pressure. He speaks of graphite as being a kind of matter distinct from carbon. This is, perhaps, misleading, seeing that graphite itself is a form of carbon. I suggest the use of the words "graphitic carbon" and "amorphous carbon." One more point—hypercritical though it may appear—is the promiscuous use of inches and millimetres. For example, he gives the size and current densities in inches and the wear in millimetres.

**Mr. N. Pensabene-Perez** (*communicated*): The

paper, I assume, is only a preliminary survey of the many and complex phenomena taking place, and I look forward to another paper from the same author in which a more complete analysis and critical survey of previous researches and formulæ would be made. A very interesting question is the determination of local surface voltage-drops in the case of non-uniform current distribution as found in practice when commutation is not theoretically perfect. According to Professor Arnold the local voltage drop in any point of the brush where the current density is $D_x$ is given by $V_x = a + b\,D_x$, in which $a$ and $b$ are constants and functions only of the mean current density in the brush. Professor Arnold uses this formula for determining experimentally the variation of the current in the short-circuited coil during reversal, which is a most fruitful investigation in order to get an insight into the process of commutation. In the case of uniform current distribution many investigators attribute the falling off of the surface resistivity with increasing current densities to heating effects. The author does not seem to agree on this point. Am I right in assuming that he adopts the theory which views the conduction of current from the brush to the metallic surface or vice versa as taking place through a great number of small arcs bridging across a film of air? Has the author investigated the effect of the brush size on the voltage drop? Turning to the more practical side of the subject, I believe the problem of brush chattering is sometimes very baffling. Certainly the reason of such a trouble must be found in the brush-holder design, in the clearance between brush and holder, in the natural period of vibration of the spring, etc. When the commutator or slip-ring surface is almost perfect the chattering of the brushes is difficult to explain. I believe chattering has its origin in an oscillatory motion of the brush about its axis vertical to the revolving surface. The brush would be slightly tilted by the frictional force so as to touch the revolving surface only with its leading edge. In this position the tangential force would be reduced and the spring tension would again pull the brush back to its normal position. The process would thus continue and a tangential vibration would set in, which by lifting the brush up and down would produce also a vertical vibration. Resonance phenomena with the spring would in some cases accentuate the trouble. This explanation is sometimes confirmed by the fact that by shifting forward the point of application of the spring on the brush the vibration can be stopped. Another point which requires great attention and to which no reference has been made in the paper, is the method of connecting the pigtails to the brush in the case of high-current high-speed commutators. In the case of a large commutator having a peripheral speed of 25 metres per second the only pigtail which gave satisfaction was one fixed to two stout plates clamping the brush by means of rivets. Many manufacturers, especially in America, in order to deal with the deleterious effects of oil vapours or acid fumes, undercut the mica between the commutator segments and fill the space with a special enamel or paste. As it is well known, oil vapours or acid fumes seem to saturate the mica with a conducting material supplied, I believe, by the brushes, with the result that the mica is eaten away by electric discharges between the bars. One of the cures is the one above referred to, which to my mind is a very elaborate and expensive one. I wonder if the author can tell us how far the material of which the brush is made is responsible for this serious trouble. This subject is worthy of our best attention and of careful chemical researches.

**Mr. P. Hunter-Brown** (*in reply*): With reference to Fig. 1, Mr. Constable and Professor MacGregor-Morris expressed doubts as to the existence of a minimum voltage below which no current would flow, and the former referred to tests he had made with carbon resting on stationary copper plates. With the collector at rest I agree that some current passes even at a very low voltage, and the contact-drop curve under these conditions would pass through the origin. With the collector running, however, the conditions are radically changed. Even at the so-called points of contact between brush and collector I think that the contact is not sufficiently intimate and continuous to prevent minute arcing, and that even when collection appears to be sparkless the current passes in the form of minute arcs. Dr. Kahn's communication to the Birmingham discussion (see page 222), is particularly interesting, coming as it does from one who has very thoroughly investigated the problem of contact drop. He has satisfied himself as to the existence of a minimum voltage below which no current will flow, and the curves given in his well-known thesis bear this out. The tests illustrated in Fig. 1 were carried down to a density of 1 ampere per square inch. Very many other tests have been carried down as far as this value, the contact drop at the minimum current still remaining relatively very high. I have not specially explored the region between zero and 1 ampere per square inch, but if an investigation revealed that the curves turned down to zero below 1 ampere per square inch it would not affect the conclusions to be drawn from the curves given in the paper for practical working conditions. Mr. Atkinson states that this minimum voltage does not exist in the case of metallic brushes. I have not made any contact-drop tests on brushes of the description he is referring to, but it is interesting to note that in the late Professor S. P. Thompson's lecture on "High-speed Electric Machinery" three contact-drop curves for copper-gauze brushes are given, attributed respectively to Dettmar, Hillman, and Arnold, and all of these show a minimum voltage below which no current flows.

Referring to Fig. 6, it would naturally be concluded from these curves that no current would flow in the graphite brush if the two qualities were mounted on the same ring. To confirm this, the two brushes were actually mounted on the same slip-ring; the graphite brush was insulated from its holder and an ammeter was connected between the graphite brush and the common terminal bar. The total slip-ring current was raised to 260 amperes, but the ammeter in the graphite-brush circuit indicated no current. Obviously if two grades are selected the contact-drop curves of

which overlap, both will carry some current, but if one is highly metallic copper graphite and the other pure graphite the proportion of current carried by the graphite brush will be negligible if not absolutely zero.

The contact-drop curves were measured by the ammeter-voltmeter method. The curves in Figs. 1, 3, and 5 were taken on a short-circuited commutator with recessed mica. Professor MacGregor-Morris expressed the opinion that contact-drop curves should be taken on a complete machine under various load conditions, and proceeded to point out some of the difficulties of doing this. An interesting article bearing on this subject appeared in the *Electrician* in 1913 by Professor Hay and others. It was considered advisable to make the contact-drop tests on an armature complete with windings. The field frame was removed and the test armature driven by a suitable direct-coupled motor. Current from an outside source was passed through the test armature and the voltage was measured at the brushes. From this was deducted the I R drop in the windings, and in the original tests the remainder was considered to represent the total contact drop at the brushes. At a later date, however, it was realized that even without a field frame the armature became the seat of a counter E.M.F. due to the fact that the reversal of the current does not follow a straight-line law, and the estimation of this counter E.M.F. proved to be rather formidable. It seems to me that the object aimed at must be carefully borne in mind, whether it is the investigation of characteristics of brushes or a certain grade in combination with a certain machine, or commutation in the abstract. From the brush manufacturer's point of view the question of primary importance is to investigate the characteristics of his various grades, and not to mask the results by introducing some effect that is dependent upon the characteristics of the machine used. For this reason it would appear advisable to use a machine of the most elementary form, that is to say, to shorten the armature until the core disappears and to use a one-turn coil of the shortest possible length; in other words, to use a short-circuited commutator with the test brushes mounted on opposite sides.

Referring to Mr. Eason's remarks, in measuring contact drops there are many disturbing factors, and until the effects of each of these can be separated out and individually controlled it is not possible to formulate laws which are applicable to all cases. Scores of curves have been taken with different grades under different conditions, and these show a great variety in shape. As Mr. Broughall aptly expresses it, the curves shown in the paper are typical and indicate the manner in which one may expect the performance and losses to vary under different conditions of pressure, peripheral speed, and current density.

The apparent variation in the coefficient of friction at various speeds has been attributed to cohesion between well-fitting surfaces, but I consider it necessary to go further than this and to offer some explanation as to why this cohesion exists. Even well-bedded brushes only make contact with the commutator at a series of points, and between these we have a series of minute cavities between brush and commutator which are normally filled with air. The suggestion is that under certain conditions when the commutator is revolving, the air is swept out from these minute cavities more rapidly than it is replaced, with the consequence that a partial vacuum is formed. If when an abnormal friction value is being observed the applied pressure is reduced to zero with the machine still running, the brush is often found to be sticking to the commutator and a perceptible pull is required to remove it. If, however, the machine is shut down before the brush is pulled off the commutator, it will be found that when the latter comes to rest the brush is not sticking to the commutator, owing apparently to the vacuum having been broken by the machine coming to rest. It is concluded that when the friction loss creeps up to an abnormal figure, it is due not to an abnormal coefficient of friction but to the fact that the total pressure is the applied pressure plus a certain atmospheric pressure. Further reasons for this conclusion are given in the paper.

Passing to the design of the brush itself, the abolition of flexibles advocated by Mr. Guy-Pell would, I am confident, be generally regarded as a most retrograde step, and the arrangement suggested appears to embody several features calculated to produce unsatisfactory operation. The loss at the top of the brush would be greatly increased, thus reducing the efficiency and producing heat just where it could not be tolerated. Moreover, the variable resistance at the top of the brush would introduce another factor tending to produce unequal distribution of load between the various brushes. The absence of a flexible imposes serious limitations upon the design of the holder. With the type recommended by Mr. Guy-Pell, at every movement of the brush the friction of the hinge pin, as well as the inertia of the pressure finger, must be overcome, and since the finger is depended upon to carry current, it would not be practicable to obviate these objections by fitting an auxiliary spring on the tip of the finger. Certainly manufacture and the problem of stock would be simplified, but this advantage is in my opinion insignificant in comparison with the disadvantages that would result. Replying to Mr. Guy-Pell's query, the pressure applied to a brush can be conveniently measured by a small cylindrical spring balance made for a suitable pressure range. When using the balance, the pull should be gradually increased and the reading taken at the moment that the grip on a piece of paper placed under the pressure finger is released.

Twisted flexibles, as pointed out by Mr. Orsettich, are to be preferred to braided, as they present a larger radiating surface and are more supple than braided. I agree with Mr. Brazil that they should be liberally proportioned, as this not only provides a margin for dealing with unduly heavy loads but also affords a valuable means of carrying away the heat from the brush. On the other hand, some judgment is necessary in the matter, and for the reason stated in the paper the flexibles should not be made unnecessarily large. I agree with Mr. Cater that if the type of connection used for attaching the flexible to the brush gives a tenfold increase of resistance at this point when

coppering is omitted, this certainly provides a strong argument for copper-plating in all such cases.

Mr. Constable has suggested a double-brush arrangement with the two brushes fitted one in front of the other. I have used this with very satisfactory results so far as effecting an improvement in commutation is concerned. I attribute the improvement partly to the extra cross-resistance and partly to the fact that one half of the combined brush can move without disturbing the other half. Mr. Atkinson and Mr. Friedlaender have referred to the fundamental difficulty of running a solid brush on a solid commutator. The double brush is a partial, but only a partial solution of the difficulty; also one brush inevitably wears faster than the other, and it is not an easy matter to design a simple and efficient brush holder to take care of the unequal wear.

Any system adopted for marking brushes should be capable of extension, and every mark should be readily expressible in words. A series of lines at various angles, as suggested by Mr. Constable, has serious disadvantages in both these respects and is also a severe tax upon the memory. The most satisfactory mark appears to be a combination of a letter and a numeral, the former denoting the class of brush, and the numeral the position in the class. If the numerals are arranged in order of specific resistance, the grade designation in itself is sufficient to give some idea of the type of brush referred to. As a rule the pressure finger and flexible occupy nearly the whole top surface of the brush, so that it becomes necessary to mark the brushes on the side.

Several speakers have referred to the question of recessing mica. It is not possible to dogmatize about this, and each machine should be considered on its merits. Of ordinary industrial motors and generators operating with commutator speeds below, say, 3,000 feet per minute, undoubtedly the great majority are running, or would run, quite satisfactorily with "flush" mica. Above 3,000 feet per minute recessing mica becomes increasingly beneficial. Above 4,000 feet per minute it has become almost universal practice to recess and, I think, rightly so. It is of vital importance, however, that the depth of the groove should not be excessive, as carbon and copper dust have a comparatively high conductivity and are liable to produce partial short-circuits if they are allowed to accumulate in the grooves, which is difficult to prevent if the grooves are made deep. The practice of making the groove V-shape is not to be recommended. It does not appear to have any value as regards preventing short-circuits, and when the mica is recessed in this way it will almost invariably be found that some of it is left adhering to the sides of the segments. Special circumstances demand special treatment, and if it is impossible to provide facilities for maintaining the grooves quite free from mica and also dust or dirt, it is advisable to avoid recessing, especially if oily vapour is present. In my experience, however, trouble very rarely arises which can be directly attributed to the mica being recessed, provided the work has been done as directed. With regard to the type of brush recommended for use with recessed mica, Mr. Cater seems to have misunderstood the paper. A "high-grade non-abrasive graphitic brush" (no limitations as to hardness mentioned) is recommended, and in this category is most certainly included the electro-graphitic class of brushes.

The use of carbon (or graphite) brushes on slip-rings has been criticized, but I think there are circumstances under which their use is fully justified. The friction loss is very small, the contact drop does not exceed about $\frac{3}{4}$ volt, and they possess the advantages referred to in the paper.

I do not share Mr. Atkinson's view that carbon brushes would not be needed to-day if slotted armature cores had never been introduced. Quite apart from considerations of sparkless running, it is by no means uncommon for owners of machines that are fitted with gauze or foliated metal brushes to scrap both holders and brushes and equip with suitable slide-type holders and carbon brushes, simply to secure the decreased wear and tear of commutators which results from this change.

The opinion has been expressed that the passage of copper from the collector to the negative brush should not be described as being akin to electrolytic action. The paper makes it clear, however, that I do not regard this as true electrolysis, as it hardly seems likely that moisture from the air could provide the electrolyte. The point that I wish to emphasize is that in addition to the mechanical abrasion and burning which occurs under both positive and negative brushes, there exists a further action which takes place under the negative brush only and causes copper to be carried across in the direction of the current flow. Under some conditions this copper is firmly deposited on the contact surface of the brushes, and is then usually described as "copper picking." The absence of the deposit on the brushes, however, does not indicate the absence of this "electrolytic" or arc effect.

Mr. Edward raises a point as to the influence of periodicity upon the rate of wear. I have not investigated this directly, but general observations made upon the behaviour of the slip-rings of rotary converters and induction motor rotors (which work at widely different periodicities) have not suggested that the rate of wear is influenced by this if the rings are non-magnetic.

Brush-potential curves are invaluable for adjusting commutating poles and giving one an idea of what is occurring under the brush, but it must be recognized that they have their limitations and are useful in a qualitative rather than a quantitative sense. The voltmeter indicates the average value only, and the current does not vary directly as the voltage. To investigate commutation we require to know what is happening in the short-circuited coil. Mr. Pensabene-Perez quotes a formula for determining the local voltage drop at any point under a brush which Professor Arnold used for estimating the current in the short-circuited coil, but the method of investigating this by measuring the I R drop in the short-circuited coil with an oscillograph (suggested originally I believe by Professor Robertson) appears more practicable. One of the oscillograph leads is passed back along the path of the armature coil selected for observation, so that

the voltage measured is the I R drop only. With regard to the influence of brush size upon contact drop, I think that in practice the contact loss is undoubtedly less with many small brushes than with few large ones, the nominal current density being the same in both cases. The actual area of contact between brushes and commutator is larger with many small brushes, and the actual contact drop is therefore less.

Referring to Mr. Edward's queries with regard to brush angles, the figures given in the paper are the result of experiment. If a trailing brush is inclined at more than 15° it is apt to wedge in the holder, due to the combined action of the spring and the friction, and a reaction brush is likely to chatter if inclined at less than about 20°.

Mr. Orsettich referred to the very high brush-tip voltages mentioned in Mr. Lamme's paper. The value of 30 volts was given as permissible by Mr. Lamme on the understanding that 90 per cent of this was neutralized by the commutating poles, leaving 3 volts to be taken care of by the brushes. These seem very high values, but Mr. Lamme was referring to extreme overloads, apparently at least 100 per cent and of very short duration.

With regard to commutating poles, it is obviously possible to proportion these so that the commutating flux is substantially correct from no load up to the load at which the first trace of saturation occurs. I think, however, it is common practice to err on the large side with the number of turns to ensure having sufficient commutating field at heavy overloads when the assistance of commutating poles is most required. Under such circumstances the value of the commutating flux is correct at one value of load only, and even Mr. Pollock speaks of adjusting the commutating-field strength to give a brush potential curve of constant value on machines of 100 kw. and upwards only. With copper-graphite brushes, as well as with other classes, the influence of current density upon rate of wear is very large. No-load tests on highly metallic brushes made under the same conditions as described on page 197 gave a wear of 0·005 mm. The duration of each test shown in Fig. 8 was 20 million revolutions.

I regret that Mr. Pollock has received the impression that I consider designers haphazard people, as nothing could be further from the truth and I am at a loss to understand what has given him this impression.

With regard to abrasion, Mr. Cater seems to have overlooked the fact that I have gone to considerable pains to show that even with so-called abrasive brushes the abrasive action is very slight. Mr. Cater states that for any particular machine suffering from proud mica the application of abrasive brushes is at times a remedy, but the case is an isolated one. With this statement I am in full agreement, and I think, therefore, that Mr. Cater's remarks on abrasion do not call for any further comment.

Mr. Friedlaender has referred to the difference in behaviour at the positive and negative brushes of small high-speed motors. An interesting note bearing upon this appeared recently in the *Technical Supplement to the Review of the Foreign Press*, which was based upon an article in a German paper. According to this, experience in running the Berlin tramways has shown that there is a marked difference in behaviour at the positive and negative brushes and arcing over is always initiated at the positive brush. The motors have four poles and the usual two-brush stud arrangement on the upper quadrant of the commutator. It was therefore found preferable to arrange the polarity of the brushes so that the commutator moved in the upper quadrant from the negative to the positive brushes, and when this change was made a considerable reduction in the number of cases of arcing over was observed. The phenomenon was explained in the following manner :—

"In an arc, particles of carbon are detached from the positive electrode and their impact on the negative electrode causes local heating. In an analogous manner, if sparking occurs under a negative brush, the arcing is concentrated on a point under the brush and spreads out from there on to the commutator, and owing to the relatively small heating on the commutator, the arc is not drawn along by its motion. On the other hand, if the brush is positive, the concentration of the arc takes place on the commutator, and by the intense local heating causes the arc to be drawn along in the direction of motion of the commutator. This fact is corroborated by cinematograph photographs made by the author. On this account arcing-over will always be initiated at the positive brush, and it is more dangerous to run the commutator from the positive to the negative brush than in the reverse direction."

Various references are made in my paper to brushes containing, or not containing, carbon in the special form known as graphite, and I think there is no ambiguity as to the type referred to in each case. With a view to greater precision, Mr. Guy-Pell suggests the use of the terms "graphitic carbon" and "amorphous carbon." Since, however, graphite is a form of carbon and some graphite is amorphous, the term "amorphous carbon" could be applied with accuracy to certain graphite brushes. The term "amorphous carbon" therefore does not appeal to me, and if greater precision is desired I would prefer to adopt the terms "graphite," "graphitic carbon," and "non-graphitic carbon" to indicate carbon brushes made entirely from graphite, partly from graphite, and wholly without graphite respectively.

## South Midland Centre, at Birmingham, 18 December, 1918.

**Mr. W. Lawson :** It is to be hoped that this exceedingly practical and valuable paper will come under the notice of all manufacturers of electrical machinery. In my opinion it rests with the manufacturers to provide their machines with brush gear so designed that when fitted with a specified form and grade of brush a much higher degree of immunity from brush troubles than has been so far obtained will be ensured. Unfortunately these troubles cannot always be detected on test, and they frequently do not arise until after the machine has been in service for some time, and it is left to the purchaser to determine by experiment

how best he can get over the trouble. This means that he is put to a good deal of expense and inconvenience and has probably had to sacrifice, by repeated grinding, an appreciable depth of the commutator bars of his machine. This is not as it should be, and I believe this paper, with the wealth of information it contains, will lead to a closer study of the question, and will ultimately result in the elimination of most brush trouble. Until that happy state is arrived at, the question of standardization should be approached with the utmost caution, On page 198 the author refers to the excessive wear sometimes produced on the top of the brush by the pressure finger, and ascribes this to electrical rather than mechanical effect. He does not state his reason for this opinion, and it is difficult to account for it in this way, as the greater part of the current passes along the flexible connection. In none of the cases that have come to my notice has there been any evidence of electrical effect. The author's experiment proving the existence of some kind of electrolytic effect is extremely interesting and important, and one that calls for further investigation. I have noticed an analogous effect, and one that is not explained or even referred to in textbooks, in meters of the mercury-motor type. In this case we have an amalgamated copper disc immersed in mercury. Two copper conductors amalgamated at the ends make contact with the mercury, and the current passes from one conductor through the mercury and the copper disc, and out by the other conductor. Under certain rare conditions electrolytic action takes place: one of the copper conductors is eaten away, and a heavy deposition of copper by transference takes place on the copper disc. I have never known of a case of this happening with a meter of less than 50 amperes' capacity, so that it appears there is a critical value of current below which no deposition can take place. It would be interesting to know if the author has observed a similar characteristic in the electrolytic effect which he mentions. Is there a point in the value of the current below which electrolytic action completely disappears? Further investigation might establish the analogy between these two effects, and also throw some light on the possibility of there being some relation between the speed of the conductor and the strength of the current determining the condition under which electrolytic effects can take place.

**Mr. E. J. Kipps:** Can the author give a reason for the statement made in the paper, under the heading of "Properties of Carbon Brushes," that a small proportion of copper in the carbon brush increases its resistance, and can he state the proportion of copper to carbon by volume at which the resistance diminished with the addition of copper?

**Mr. W. F. Higgs:** On page 194 and also, I think, elsewhere in the paper, the author refers to atmospheric conditions. We had a case of a 25-h.p. motor at 460 volts, the peripheral speed of the commutator being about 3,000 ft. per minute. The machine was installed on two girders, 8 ft. above the floor, about two years ago. The brushes would run about 10 days and then collapse all at once. Many different qualities of brush were fitted, with no improvement. The commutation with regard to sparking was perfect, and this was a repeat machine, of which we had made dozens of the same construction mechanically and electrically. The machine was taken off its girders and put on a concrete foundation in the same shop, and the trouble still continued. It was moved into another shop, and has been running satisfactorily with the same brushes for 12 months. A second machine was installed where the first one was taken from, an exact duplicate, and the same trouble occurred. We think we are right in putting this down to atmospheric conditions. On page 198 the clearance of 0·2 mm. and 0·3 mm. in brush holders suitable for taking a brush 1 inch × ½ inch or larger Link One, Morganite, is, I consider, not sufficient. The author mentions in several places about the undercutting of mica. This is not a practical job to be done by machinery, and is rather a tedious job by hand. It is quite a good arrangement to build the commutator up with mica about ⅛ inch lower than the bars, and it can be done if suitable tackle be used. We find it good practice to fit the brushes to suit each individual machine as it goes on to test. There is one other question I should like to ask the author, namely, what is his opinion of die cast brush-holders? Has he had any experience with them, and, if so, is he in favour of them or not? I am inclined to adopt them, but I am afraid of crystallization of metal taking place, due to vibration or some other such trouble. Is there any foundation for my fears?

**Mr. W. N. Y. King:** I notice that no reference has been made to a well-known property of carbon which has an important bearing on the subject under discussion. I mean the negative temperature coefficient, i.e. that as the temperature increases the electrical resistance decreases. Two prominent examples of this effect have come under my observation in large direct-current generators, one of 1,500 kw. and the other of 1,000 kw. capacity. In each case trouble was experienced with commutation at full load and over. Severe sparking and flashing occurred and overheated the brushes. One brush in a row would take more current than the others and get red hot, with cumulative effect due to the negative temperature coefficient, until the brush or flexible lead burned away. Then another brush would undergo the same process, and so on until it became questionable whether the machine would run till shutting down time without renewing the brushes while the machine was on load, and this is not a desirable thing to do. In one of the cases mentioned the trouble was eliminated by substituting Morganite, Link Three, for carbon brushes. It would be interesting to know whether the temperature coefficient of the Morganite brush is negative, and how it compares with carbon.

**Mr. F. Forrest:** It is well known that the thermal conductivity of carbon and graphite materials is very low, and it is quite possible for the forward tip of a carbon brush to be very hot, in fact glowing, whilst the rear edge of the brush may be comparatively cool. This great difference in temperature causes the brush to buckle to a certain extent on its face, and is one of the causes of sparking taking place. In order, therefore, to get the heat away from the forward tip of the

brush, it is advisable to use a metal brush-holder of the box type, which extends down to even something under $\frac{1}{4}$ inch of the commutator, and this metal box can assist in conducting the heat away from the hot portion of the brush and effect a great improvement in the commutation of the machine. It is also well known that the contact resistance of the positive brush is higher than that of the negative brush, and cases are known where the commutation has been quite satisfactory with a certain type of brush when connected to the positive pole, but has been unsatisfactory when the same type of brush has been connected to the negative pole. As a general rule the negative brush will always be found to be hotter than the positive, and the face of the negative brush will be more highly polished than the face of the positive brush. The expansion of the negative brush will therefore be greater than the positive, and in connection with this it would have been interesting if the author had included in the paper the temperature coefficient for expansion for brushes made of carbon or graphite material. It is of the greatest importance that all brushes on the same machine should bear on the commutator with equal pressure, and I can strongly support the author's suggestion that the brushes should be individually adjusted with a spring balance. This method of adjusting the brush pressure has been in use for some years in the stations of one large supply undertaking in the Midlands, with very beneficial results.

**Mr. A. T. Bartlett** (*communicated*): Generally I agree with most of the paper, and my remarks will, as it were, only underline a few of the author's points. I should like, however, to caution members against using some of the curves given in the paper for purposes of design of machines, as the curves I refer to are, as the author points out, the results of experiments made under laboratory conditions such as are not met with in general practice, and are of greater use to the manufacturers of brushes than to the designers of machines. I am much interested in the author's theory of air suction being the cause of the increase in the coefficient of friction at lower speeds. With perfect laboratory conditions it is quite conceivable that there may be a measure of "optical" contact, as it were, between the brush and the commutator, but, as the author points out, one is not likely to get such conditions in practice. I suggest that another reason for the shape of this friction curve is that brushes are not, in practice, really in good contact all the time, and that at the higher speeds this imperfect contact is increased. I will describe an experiment which I made some 12 years ago when engaged on the commutation difficulties of direct-current turbo-generators. A commutator with all its segments connected to a common ring was mounted on a special shaft. The common ring was connected to a slip-ring, so that current from an outside source could be passed into the commutator and leave at the brushes pressing on the commutator in the normal manner. Very special attention was given to the truth, surface, and balance of the commutator at full speed, and also to the bedding of the brushes. Readings were then taken with, as far as I can remember, the following result: One brush was first put down and loaded to its normal current density, the drop was measured, and we will represent it by unity. A second brush was then put down and the current doubled in order to eliminate any effect of change of current density. The drop was then roughly one-seventh. A third brush was put down with less change, the figure being then about one-fifth. I think the only explanation can be the one I have given, viz. that brushes are off the commutator for a considerable time, and this would cause the retarding effect of the brush to be decreased. It would be interesting if the author would describe briefly the method he adopted to measure the friction coefficient. This leads me to the question of the size of brushes and the design of brush-holders. The ideal conditions for perfect running as regards these are an infinite number of brushes of no mass, and holders with no mass in their moving parts. As designers we have to compromise, and I favour a short brush of either $\frac{3}{4}$ inch or 1 inch in axial length, and a clock spring with its end pressing directly on the top of the brush, as fulfilling most completely the conditions of light moving parts. In my opinion a spring can be too lively or resilient, a slight hysteresis being an advantage. Current density is undoubtedly a factor in the wear of both brush and commutator as well as in the commutation, but, as the author says, the current density in a brush can seldom be measured by the current it delivers to the external circuit. In the early days of carbon brushes I once had a machine in which the brushes were loaded, nominally, to 35 amperes per square inch—the makers' rating—but they sparked and glowed excessively. I changed to brushes of half the width, thereby bringing up the nominal density to 70 amperes per square inch—double the makers' rating—with quite satisfactory results, and those machines ran well for years. Here apparently we had increased the nominal density, but actually had decreased it. Much attention is now being given to the current distribution in brushes by designers of motors and generators. It is quite common to find machines, even when they apparently commutate perfectly, running with brushes in which the current density departs greatly from being uniform over the section, the variation being easily as much as 1 to 5; with a well-designed machine and correctly proportioned and adjusted brushes and interpoles, this departure may often be reduced to 1 to 1·5. I have gradually come to the conclusion that the differences in the behaviour of two similar machines, as mentioned by the author, is very often due to want of care in the adjustments referred to above, which results not only in perhaps poor commutation but certainly in greater wear of both brush and commutator. As an instance, two turbo-generators made at the same time were running side by side. One of them gave no trouble and the other was not nearly so satisfactory, there being a slight sparking and much wear. After much experimenting the brush density was improved and there was no further difference between the machines. The author mentions the presence of symptoms suggestive of electrolysis, and attributes copper "picking" to this phenomenon. No doubt it does, but I am

inclined to think an irregular current distribution is more often the larger factor. Electrolysis, or a pseudo-electrolytic effect, undoubtedly occurs, and I believe I was one of the first to come across a really definite case some 10 years ago. A heavy-current low-voltage generator was fitted with copper-graphite brushes having a large copper content. On test, after running about 10 hours the commutator developed a salmon-colour matt surface, and the brushes, if not the commutator, began rapidly to be transferred in the form of powder to the bedplate and machine generally. The trial had to be stopped, and afterwards a careful examination of the brushes and commutator was made. At rest the appearance of the commutator was as stated, the surface of the positive brushes was quite metallic and bright, whilst the negative brush surface looked as though it had been painted with dead lamp-black. No trace of the copper content was visible; it had apparently been transferred by the current to the commutator exactly as in normal electrolysis. The negative brushes were replaced with graphite brushes, and fortunately for the makers it ran most successfully, as the commutator would have been too hot with all graphite brushes. The author remarks on the importance of having similar pressures on all brushes of a machine, as this has an importance which even skilled attendants and erectors do not fully appreciate. I am glad he has referred to the common error of assuming that hardness and abrasiveness are synonomous terms. I have known apparently the most innocent-looking soft brush wear a commutator in the most aggressive manner, certainly many times faster than the most abrasive hard brush I have ever met.

**Dr. M. Kahn** (*communicated*): I should like to hear the author's opinion regarding the physical explanation of current transmission between brush and collector. The following facts give certain indications about this question The voltage drop between the collector and the brush is comparatively constant over a large range of current density, and shows a minimum value below which no current passes. If one compares the curve for the drop given in Fig 1 with corresponding curves of electrical arcs one finds a great similarity. Another indication is the phenomenon usually called copper picking, described in the paper. It is a very disagreeable trouble which is sometimes experienced on high-current machines On the face of it this feature looks like an electrolytic action. It is, however, so far as I know, quite independent of the presence of moisture or traces of acid, which are ordinarily present in connection with an electrolytic process. A similar action is also found in the electric arc, the material of one electrode being carried in the direction of the flow of current to the other electrode. A third indication is the difference in contact drop between the positive brush and the collector and the negative brush. I find that the author has not gone into this question and I should be very interested to hear his observations about this point. The phenomena mentioned show that the flow of current from a carbon brush to a collector differs entirely from the conduction of electrical energy along a metallic conductor, which follows the ohmic law. It seems to take the form of a large number of minute electric arcs which in the ordinary way do not contain sufficient energy to be visible to the eye. With increasing voltage between brush and collector the energy in these arcs increases very much more than the voltage, as can be seen from Fig. 1. An increase from 2 volts to 2·5 volts doubles the current in the contact surface; that is, an increase of 25 per cent in voltage produces an increase in energy of 150 per cent. Due to the large increase in energy the arcs become visible, when the voltage between brush and collector is increased beyond a certain limit, in the form of small sparks, which get larger the higher the voltage. The arcs or sparks can be observed in various intensities on badly collecting machines. They are, however, always present, although they may not be visible, wherever current passes from a brush to the commutator, and they may cause wear of the commutator and brush, copper picking, and disintegration of the brush surface, even though the machine may appear to collect perfectly. It follows from these remarks that the phenomena of sparking depend on the voltage drop at any point between the brush and collector, and this can easily be proved by measuring this drop when sparking occurs. The selection of a suitable brush for a given dynamo or motor does not offer any difficulty on ordinary electrical machines. In special cases like high-speed dynamos geared to turbines or rotary converters, the demands on the brushes are very exacting. The difficulties encountered in such cases are, however, often more of a mechanical than of an electrical nature. The principal requirement is to get a brush with low friction coefficient and small inertia which will ride smoothly on the commutator and not chatter. The brush should be self-lubricating, as resort to commutator lubricants only effects temporary improvements in case of brush vibration, and the application of lubricants at short intervals is undesirable. Apart from the fact that a machine requiring constant application of lubricants would rightly be regarded as a burden by the running staff, the lubricant has a tendency to accumulate at certain parts of the brush gear and to mix up with carbon and copper dust. Finally I should like to refer to the question of standardization. If one approaches this question in wholesale fashion and tries to arrive at standard brushes for everybody and everything, the task appears hopeless. A better way is to select a few suitable sizes of brushes as standard sizes and settle definite dimensions of flexibles for these brushes. All manufacturers of electrical machinery could then be asked to adopt these as far as possible on new types which are brought out, and in any other case where it can be done. The manufacturers of carbon brushes would have to select certain grades of brushes which are generally used in commercial work, and keep a stock of these brushes in all standard sizes. If the manufacturer knows that he can get these brushes any time from stock it will be a big inducement for him to adopt them whenever possible, and it would of course be a great advantage for motor users to be able to buy such standard brushes in case of replacements. This would presumably in time lead to a more and more universal use of the standard

brushes. I understand that steps have been taken to arrive at a satisfactory solution of this problem.

**Mr. P. Hunter-Brown** (*in reply*): The opinion expressed in the paper, that the wear which sometimes occurs on the top of a brush is more an electrical than a mechanical effect, is the outcome of actual observations. It is true that the resistance via the flexible is very much lower than via the finger, but the latter will carry a small amount of current, and a very little current greatly exaggerates any tendency there may be for wear to occur. If there is extremely severe chattering a brass plate affords more protection than a piece of insulating material. Provided, however, there is no unreasonable chattering, insulation stands better than a brass plate; in fact, the pressure finger will often bore its way into a brass plate as readily as into the brush material itself. In traction work the pressure fingers sometimes produce heavy wear on the tops of brushes that are not fitted with flexibles; in such cases the addition of flexibles has very greatly reduced the wear. Replying to Mr. Lawson's query, I have not made any tests to determine whether there is a critical current value at which the "electrolytic" effect disappears.

The increase in resistance produced in a brush by the addition of a small proportion of copper seems to be due to its homogeneity having been broken up to some extent, the particles of copper apparently introducing a series of minute contact resistances. The proportion of copper required to produce an increase in conductivity is influenced by the other ingredients of the brush and the method of manufacture. Mr. Higgs states that a clearance of 0·2 mm. in the thickness and 0·3 mm. in the width is not sufficient for a Link One brush. These figures were intended to apply to ordinary carbon and graphite brushes. Link One is a quite special brush and must be made to a special scale of clearances depending upon its size. Regarding methods for recessing mica, I have found a hand-applied circular milling cutter, motor driven, very satisfactory, and, failing this, good work can be done by hand with a portion of a hack-saw blade suitably mounted in a wooden handle. Even if the commutator is built with the mica below the surface the question of recessing the mica will recur when the copper wears down. I have not had any experience of die-cast holders, but have heard fears expressed in more than one quarter similar to those voiced by Mr. Higgs.

Mr. King mentions two interesting cases of what is often described as selective action. It was no doubt caused by a decrease in the contact drop, as well as in the resistance of the material itself. The temperature coefficient of "Link Three" material is also negative, and I think the fact that this grade eliminated the trouble on one of the machines was probably largely due to the reduction of circulating currents and the better distribution of current across the face of the brush produced by the special characteristics of this grade.

Mr. Forrest and Dr. Kahn have both referred to the difference in contact drop at the positive and negative brushes. The following figures relate to a test on carbon brushes working at 10 amperes per square inch and mounted on a commutator running at 3,500 feet per minute, mica recessed, the pressure being 2 lb. per square inch.

| Contact Drop in Volts | | | Direction of Current |
|---|---|---|---|
| Brush No. 1 | Brush No. 2 | Total | |
| 0·73 (neg.) | 1·18 (pos.) | 1·91 | Metal to Brush No. 1 |
| 1·11 (pos.) | 0·80 (neg.) | 1·91 | Brush No. 1 to metal |
| 0·76 (neg.) | 1·11 (pos.) | 1·87 | Metal to Brush No. 1 |

The interval between tests was very short; the contact drops in the third test do not quite return to the same values as in the first test, but the figures appear to show that the direction of current had a definite influence upon the contact drop. On the other hand, other tests made with carbon brushes in a similar way have shown a greater drop at the negative than at the positive brush. I have read statements from various sources which agree that there is a difference in the contact drop at the positive and negative brushes but do not agree as to which is the greater. One or two observers (including Dr. Kahn, I believe) have noticed that the greater drop does not always occur at the same pole, and this accords with my own experience. Speaking generally, with reference to a very large number of tests each lasting several days, in the majority of cases with copper-graphite the drop at the positive brush is much greater than at the negative, but with carbon brushes the drop is greater at the negative than at the positive perhaps more often than not, but I do not find any universal rule to be applicable.

Mr. Bartlett mentions several very interesting points in his communication. It is unfortunate he was not able to give the actual contact-drop figures taken on the turbo-dynamo commutator to which he refers. A variation as large as 7 : 1 when a second brush was added seems very difficult to account for, and it would appear that the increase in contact drop following the fitting of a third brush must have been due to some extraneous cause. The friction measurements referred to in the paper were taken by a combined electrical and mechanical method. The test brushes were fitted in brush boxes at the end of a carefully balanced lever mounted on ball bearings. The friction force could be neutralized by adjusting a spring balance, the amount of the force being read on the balance. As a check on this, the difference of input to the motor with and without the test brushes in place (after certain small corrections had been made) gave a measure of the friction force. Mr. Bartlett gives definite figures relating to the distribution of current in each individual brush. These figures are very interesting, but a description of the method used in obtaining them would have very greatly added to their interest.

# PROCEEDINGS OF THE INSTITUTION.

## 620TH ORDINARY MEETING, 9 JANUARY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 19th December, 1918, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. A. F. Harmer and E. S. Shoults were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

### ELECTIONS.

*Member.*

Dalziel, James.

*Associate Members.*

Adcock, FrancisWilliam D.
Addison, William James.
Atkinson, John.
Barnett, Eustace Bertram.
Blythe, John Edwin L.
Bostel, Alfred Charles.
Burrell, Fountaine Meers.
Cooper, William John.
Cowie, John Robert.
Dashwood, Henry Edwin.
Dutton, Harry.
Fraser, Andrew.
Garstang, Frank Leslie.
Good, Reginald Sydney.
Halton, Edward.
Harris, Robert Charles.
Jessop, Louis.
Loria, Albert.
Mansfield, Arthur Norman.
Miles, Richard Alwyn.
Pallott, Charles Frederick.
Porter, William James H.
Prior, Ernest Stanley.
Roberts, Arthur Harry.
Snow, Louis Aubrey.
Stiver, John Leslie.
Symonds, Percival Herbert
Walker, Hubert William.
Wingate, William Richard N. C.

*Associate.*

Hardie, Robert.

*Graduates.*

Barraclough, Frank.
Lipman, Chmoul-Leib.
Meiklejohn, Donald Biggam.
Phillips, Reginald Mackenzie.
Pinheiro-Chagas, Gustavo.
Walker, James.
Williams, John William.

*Students.*

Beaver, Eric James.
Cooper, Frank.
Hambleton, Charles Ernest.
Lee, Wen-Yin.
Lodge, William Maurice.
Nixon, Leslie Reginald.
Ord, William Leslie.
Pierce, Eric Owen.
Sanyal, Kshitish Chandra.
Simpson, William.
Wilson, Joseph Arnold.

### TRANSFERS.

*Associate Member to Member.*

Henderson, Andrew.
Lincolne, Gerald Bruce.
MacDougall, James Kenneth.
Marr, James Brown.
Pensabene-Perez, Nicolo.
Teasdel, John Edwin.
Williamson, George William, M.C.
Wiming, Wilfrid Lawson.

*Associate to Associate Member.*

Just, John Stephens.

*Graduate to Associate Member.*

Bowey, Norman.
Broadwood, Leopold Alfred T.
de Hollanda, Raphael.
Dent, Lancelot Brown.
Edwards, Edward.
Ferguson, Alexander Victor.
Hughes, Llewelyn.
King, Edward Thomas.
Krasemann, Herbert Anthony.
Marsden, Thomas.
Mortimer, Matthew Johnson.
Sparrow, Herbert Robert.
Spendiff, Bertram George.
Wyatt, Matthew Montagu.

*Student to Associate Member.*

Bell, Hugh Glover.
Lakeman, Bertram.
Martindale, Robert Ruthven.
Pocock, Lyndall Crossthwaite.
Potter, Edgar.
Richardson, William Pearl.
Tindall, Frederick Joseph, M.Eng.
Whitehouse, Maurice Hazel.

*Student to Graduate.*

Birch, Ewart Emlyn, Eng. Sub-Lieut., R.N.R.
Brigg, John Ellwood.
Craig, Herbert Sidney.
de Melho-Vilhena, Themistocles.
Dennis, Benjamin.
Devonald, David Benjamin.
Entwistle, Gertrude Lilian (Miss).
Fiske, Alfred Reginald.
Gordon-Campbell, William Francis.
Guthrie, Ernest Alfred.
Harben, John Edward.
Harrison, Geoffrey Alan.
Kennedy, John Gilbert.
Midgley, Harry, B.Sc.
Norburn, William Henry J., Lieut. R.E. (T.).
Ostler, Peter, Lieut. R.E. (T.).
Pollard, Herbert.
Richards, Cleveland Garfield.
Salisbury, John Harrison.
Soper, Vivian.
Travers, Archibald, Lieut., R.A.F.
Wheeler, Philip John C.
Whitney, John Stuart.

Mr. M. B. Field, O.B.E., Member, delivered a lecture entitled "The Navigational Magnetic Compass as an Instrument of Precision."

A vote of thanks to the lecturer was proposed by the President and carried with acclamation.

The meeting adjourned at 7.35 p.m.

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# THE FUNCTIONS OF THE ENGINEER: HIS EDUCATION AND TRAINING.

By Bt.-Lieut.-Colonel W. A. J. O'Meara, C.M.G. (late Royal Engineers), Member.

(*Paper received* 14 *December*, 1918; *read before* The Institution 13 *February*, *before the* Western Centre 27 *January*, *and before the* Scottish Centre 11 *March*, 1919.)

## Introduction.

The great World War, recently concluded, has given a striking illustration of the exceedingly important rôle being played, in our own time, by the engineer in the economics of industry and commerce throughout the world. To-day there can be few who are ignorant of the extent to which the engineer has contributed to the victory which has crowned the efforts, continued over the space of four years and more, of the Navies, Armies, and Air Forces of the associated Powers; few are there who can be oblivious of the fact that the material prosperity and comfort, in modern times, of the dwellers in practically every quarter of the globe are essentially due to the activities of the engineering profession in the wide field covered by it in the three recognized branches of civil, mechanical, and electrical engineering. Nevertheless, the status of the engineer is still a dubious one; at least it is so in this country, and there continue to exist in some quarters considerable misunderstandings as to his true functions and responsibilities.

The world is now about to enter upon a new era and upon a different order of things from that to which the public had become accustomed prior to the autumn of 1914. The disturbances caused in the relations of mankind by the great conflict in arms have brought into existence new problems for settlement other than that connected with the redrawing of the map of the world upon which the minds of many appear to be concentrated to the exclusion of all else. Among the other problems which, it seems to the author, must receive early attention, is the one connected with the better and more efficient utilization, in many of our industries, of the skill, knowledge, and experience of the engineer, than has been the case in the past in this country. But before this can come about, some re-adjustments are essential in the boundaries hitherto set up between the two broad classes of responsibilities in connection with the conduct of industrial and commercial enterprises of a technical kind, namely, those connected with the so-called "economics of policy," on the one hand, and with the so-called "economics of practice" on the other.

Unfortunately, an opinion has prevailed to some extent in this country in the past that the treatment of the problems which present themselves in a technical undertaking or enterprise fall under two separable, distinct, and independent heads, namely, the "technical" and the "administrative": it has been assumed that the "technical" problems of an undertaking alone constitute the domain of the economics of practice, whilst the consideration of every other problem, financial, commercial, or administrative, belongs exclusively to the realm of the economics of policy. Engineers have to a large extent acquiesced in the past in this view of the division of responsibilities in technical undertakings, and so also has the teaching profession; the consequence is that schemes prepared in connection with the education and training of the engineer have hitherto been framed for the purpose of meeting the condition of affairs alluded to above.

## The Engineer's Education in the Past.

Fortunately, the curricula of the courses of instruction now laid down for engineering students are not, like the laws of the Medes and Persians, absolutely permanent, fixed, and immutable in character or scope. Much has been done in the past with a view to making the instruction provided for engineering students conform to the up-to-date requirements of each period of engineering history. It is now many decades since it came to be fully recognized that the school of "haphazard experience" was a most wasteful and unsatisfactory one in which to meet the needs of the young men desirous of adopting the engineering profession as a career. *Faute de mieux*, the "school of apprenticeship" was next tried, and many eminent engineers have in the past been educated and trained in this school: it possesses many excellent features, but, in its turn, it has been found inadequate by itself

to meet the needs of modern commercial and industrial enterprises. To the recognition of this fact has it been due that an entirely new class of schools and colleges has, practically within our own lives, sprung up in many parts of the British Isles for the express purpose of providing instruction in technical subjects for engineering students. Such schools and colleges can be a means only of providing a young man with experiences and knowledge preparatory to his entry upon the activities of commercial and industrial life: the professors cannot turn him out a "complete engineer" at the end of the normal course of instruction provided at any of these institutions.

The nature and scope of the instruction which should be given at these schools and colleges, and the character of the results that have hitherto been obtained by them have, as is well known, been much debated in the past, and indeed are still being debated. One fact emerges prominently from these discussions, namely, the absence of unanimity on the part of those well qualified to express an opinion thereon, the employers, as to the real value in the production market of the engineering graduates immediately on the completion of the normal college course, i.e. at the time that many embryo engineers seek to enter into their first contract of service or employment.

In this country, hitherto, the discussions on the subject of the instruction which should be given to a student in order to prepare him for the duties of the engineering profession have been largely, if not exclusively, concerned with the question of his technical education and training, in the narrowest sense of the term, i.e. it has been usually confined to the scientific aspects of instruction in technology.

### The Engineer in Foreign Countries.

In some foreign countries a wider view has been taken in the matter of what an engineer's education should comprise than has been the case in this country, and it has been suggested that the instruction given to engineering students during the normal college course should include such subjects as accountancy and book-keeping, banking, mercantile law, political economy, repairs and depreciation, sociology, etc., and, as is well known, in some of the American Institutes of Technology, a department of "business engineering" has existed for very many years and has provided, during the normal course, instruction for engineering students in many of the subjects enumerated above. This difference in the scheme of the education of the engineer provided in the United States of America, compared with that existing in this country, is due, no doubt, to some extent to the fact that the nature and scope of the engineer's responsibilities as recognized in the former country are not identical with those which limit the functions of the engineer in the British Isles as indicated earlier in this paper. The American engineer occupies, as a rule, a far stronger and a much more important position in the economics of industrial and commercial life than that accorded to his confrère in this country. The same is true as regards the position of the engineer in many of the countries on the continent of Europe, where the engineer's knowledge and skill are appreciated practically at the same value and to the same extent as in the United States of America.

It is interesting to note that the question of the education of the engineer has recently been under discussion before the Société des Ingénieurs Civils de France. This important body so fully recognizes that the education of the engineer must keep pace with the demands likely to be made in the immediate future upon the profession that, on the occasion referred to, it passed a resolution recommending that instruction in administrative subjects should forthwith be made obligatory for all students attending courses of instruction in the higher schools of civil engineering in France.

### Need for Reform in Engineering Courses in British Colleges and Schools.

In the days of the sharp competition in the sphere of international trade that lie before the nation, it would be folly were we to ignore what is taking place in educational matters in other lands which will continue, as in the days before the war, to be our competitors, and indeed serious competitors, in the fields of industrial and commercial economics. The certainty of the knowledge, that international competition in trade will be far keener in the future than ever it was in the past, should prove a sufficient inducement to us to adopt every conceivable measure whereby an improvement can be effected in the education and training of those who will have to play one of the most important rôles in the economic warfare of the future, namely, the members of the engineering profession. The need for reform in this country in the present scheme of education and training provided for the engineering student exists, however, on other grounds also: it has already been pointed out that the scope of the engineer's education and training is wider in foreign countries than in this country. Further, it has been suggested in an earlier part of this paper that the existing boundaries in our industrial and commercial undertakings between the so-called "economics of policy" and the so-called "economics of practice" require to be re-adjusted. This re-adjustment is bound to take place sooner or later; it is only a question of time. Such a re-adjustment is necessary as well in order to promote efficiency in all our technical undertakings in the national interest, as also with a view to enabling the British trader to hold his own in the coming struggle for supremacy in the economic sphere. The scheme of education provided for the engineering student in this country should aim at covering as wide a field as that covered in similar cases in any other country. This is necessary in order that the British engineer may properly discharge the whole of the duties which may devolve upon him at the present day in whatever part of the world he may decide to begin his active career, and also in order that he may be qualified for the wider responsibilities likely to fall upon the engineer's shoulders when he is called upon in this country, under the stress of competition, to occupy a position in our industrial and commercial undertakings in every way similar and equivalent to

that assigned to his confrères in other parts of the world.

### Scope of the Engineer's Responsibilities.

It is really not necessary to propound abstract theories as to what subjects should, and what should not, be included in the recognized curriculum of an engineering course. The only satisfactory method for dealing with this matter which can be adopted, it seems to the author, is to proceed on the assumption that the specialized education and training of the engineering student should be designed with a view to qualify him to fill, with the highest efficiency, the functions of the position in which he will find himself on obtaining his first responsible appointment after the termination of his complete course of instruction.

Fortunately, the considerations affecting the practice of the engineering profession do not consist of a series of theoretical premises; on the contrary, the practice is concerned with a number of well-known operations which are based on solid facts and require the adoption of a certain procedure to attain the results aimed at. The true object to be sought after in framing courses of instruction for the engineering student should be, the author apprehends, to familiarize and to provide him with practical and immediately useful knowledge concerning the nature of the various kinds of tools, machinery, and plant met with in ordinary engineering practice, their special uses and operation; the principles and technical details involved in designing engineering structures, machinery, and plant, in order to attain the ends sought in any particular case; the properties and special uses of the materials employed in the construction of engineering works, and in the construction and operation of machinery and plant; the procedure that must be adopted to procure materials, tools, machinery, and plant; the procedure that must be adopted to secure the construction of works of various kinds, the installation of machinery and plant, and their operation. A further object to be aimed at in the scheme of instruction prepared for the engineering student naturally should be to render him conversant with the legal aspects of his responsibilities, and the probable consequences should he fail to fulfil his obligations either to his employer or to others with whom he may be brought into contractual relations either as a principal or as an agent.

Many of the matters referred to above as coming within the scope of the instruction which should be provided for the engineering student fall, as will be readily recognized, in the category of technical subjects—in a narrow sense of the term—in respect whereof ample and excellent provision is made at many centres in the British Isles. On the other hand, little, if anything, has been done to provide instruction in those matters, mentioned above, that are not directly and intimately associated with technology.

But an examination of the history of the engineering profession shows distinctly that it is quite wrong to suppose, as some do, that at any period of the world's existence has the engineer confined his attention in his professional capacity to what are known in a narrow sense as the technical problems connected with his calling. The misconceptions on the subject, where they exist, appear to arise from the fact that, in the era prior to the "industrial revolution," the skill of the engineer was very largely devoted to the design and construction of stationary structures, such as bridges, viaducts, aqueducts, reservoirs, docks and other harbour works, etc.; and, as a rule, on the completion of a structure of one of the kinds in question, the engineer practically disappeared from the scene of his labours in order to devote his time and attention to works of a similar character in some new locality or country. However, at the initiation of a project of one of the kinds in question the technical, or quasi-technical, aspects of the engineer's work in relation thereto admittedly included the selection of the precise site for the bridge, aqueduct, or other structure of the kind referred to, as well as all matters connected with the designing thereof. Further, it was also his duty to prepare the specifications, estimates of cost, to call for tenders, to enter into the necessary contract or contracts, to supervise the performance of the contract or contracts, to measure up the work, to come to an agreement with the contractor as to the inclusion or exclusion of claims for payments in respect of "extras," etc., and finally to issue the certificates on which alone the contractor or contractors were entitled to receive payment for the work or works executed by him or them.

It was principally the laws of statics with which the engineer was concerned in those days in connection with the technical aspects of his work, and its character was in consequence such that when the work in question was completed, whatever it might be, e.g. a bridge, a reservoir, or other stationary structure, it could be safely handed over by the engineer to his employer or his client. Once the work passed out of the engineer's hands he could leave it to others, even though they possessed no technical qualifications, to take complete charge of his handiwork and to exploit the same, practically without his, or another engineer's, continuous assistance, for the purpose of reaping any financial advantage that might be derivable therefrom.

However, the whole character of the great majority of engineering enterprises of our own time is vastly different from those in existence even a century, or less, ago. The engineer is no longer concerned almost exclusively, as of yore, with the design and construction of stationary structures, the important commercial problems in connection wherewith concerned principally their first or capital cost, the placing of the first contracts for the work, and the supervision of the due performance of these contracts. Far the greater part of the work that the engineer is called upon to deal with to-day consists, as is well and widely known, in the construction of works and in the development and exploitation of enterprises such as railways, electric tramways, electric lighting undertakings, telegraphs, telephones, industrial workshops, etc.; works and enterprises which require the provision and maintenance of machinery and plant, the essence of a great part whereof is motion and in every part whereof expansion, progress, and growth are the predestined concomitants.

These enterprises present not only technical problems of great complexity requiring solution, but also the equally important commercial and administrative problems relating to running costs, repairs and depreciation, capital outlay *in futuro*, as well as *in præsenti*, the organization of the undertaking and the personnel connected therewith, the control and management of the staff, etc. The engineer also still remains responsible, as in the past, for inviting tenders for the work, scrutinizing the tenders when received and advising on them before acceptance, and, finally, in supervising the work, dealing with the contractor's claims, and in settling the many points of detail in relation to the contract which spring up as the work progresses. However, instead of having to deal with a single set of contracts only at the initiation of a scheme, the engineer has nowadays often to consider the question of the letting of a series of contracts at various intervals of time and at dates that have to be opportunely chosen in relation to the state of the money market, the ruling prices of raw materials, and in relation to many other factors of high importance. Thus it is that in a double sense the work which engages the attention of the modern engineer has ceased to be stationary in character; in consequence, by reason of the fact that the laws of dynamics are in full play continuously in, at least, some part of the machinery and plant for the provision of which the engineer has been responsible, and also in view of the circumstance that in a modern technical undertaking the need is continually arising for additions to be made to the existing machinery and plant, and for the replacement of obsolete types of machinery by that which is more economical and up-to-date, the engineer cannot, as was formerly the case, safely transfer the custody of his handiwork to those possessing no technical qualifications. On the contrary, in order to make a technical enterprise a financial success, and in order to prevent disasters and accidents to human beings owing to a mishandling of modern machinery and plant, the engineer must continue to concern himself, as long as the same continue to exist, with every phase and aspect of their operation, and at the same time he must control and direct into proper channels the energies of the highly skilled persons who are required for the purpose of assisting him in the conduct of the undertaking and to aid him in the performance of his onerous duties.

The above statement briefly sets out the usual occupations of a modern engineer in relation to the important technical undertakings of our time; it contains nothing that is not already well known and very familiar to every member of the engineering profession. The recital of the operations to which allusions have been made may have conjured up in the memories of some engineers visions of toilsome hours spent, and trying experiences passed through, in connection with this or that scheme or job. But how many engineers are there who have for a moment given thought to the questions: How much of the work involved in carrying through a large and important engineering scheme is really technical (in a narrow sense of the word)? How much of what has to be done by the engineer to initiate such a scheme and to carry it through to completion is based exclusively on the knowledge acquired during the normal college course of instruction? What knowledge other than that comprised in the normal college course was it necessary to call in aid in order successfully to grapple with the scheme as a whole and to see it through to completion?

The answers to the above questions are, it seems to the author, of great importance at the present day from the point of view of determining what shall be the character and scope of the education and training to be provided in this country for engineering students.

### The Six Functions in a Modern Undertaking.

Monsieur Henri Fayol, a distinguished French engineer, who is now the Director-General of the Société Anonyme de Commentry Fourchambault et Decazeville, and who is also closely associated in other ways with the metallurgical and mining industries of France, has recently given his countrymen the benefit of his long experience as an administrator and an engineer in an address which he delivered in Paris in the winter of 1917. A study of what Monsieur Fayol said on the occasion mentioned provides convincing evidence that the idea, which has prevailed in some quarters in this country in the past, that there exist in relation to engineering problems two absolutely separable and independent aspects, namely, the administrative and the technical, is incorrect; Monsieur Fayol points out that as a matter of fact the several operations connected with every enterprise fall into six distinct groups, namely:—

(i) The Financial.
(ii) The Commercial.
(iii) The Technical.
(iv) That of Custodianship.
(v) That of Book-keeping.
(vi) The Administrative.

Whatever the character of an enterprise, whether it be simple or complex, small or large, commercial or industrial, these six groups or essential functions will always be present therein; and the responsible engineer in every undertaking must be concerned in his professional work with every one of these groups or essential functions.

In order to demonstrate what is comprised within the ambit of each of the six functions in question, the author has collected a number of items or transactions—the list is by no means complete—and has classified them in a Table, each item or transaction being placed under its appropriate group or function (see Appendix 1). This Table does not illustrate any particular type of enterprise; it is intended to cover the transactions taking place in all kinds of commercial and industrial undertakings. Further, it must not be assumed that an operation corresponding to each one of the items enumerated in Appendix I must necessarily occur in every undertaking; nor is it the case that every item under the technical group refers to a transaction or operation for which an engineer must necessarily be responsible in his professional capacity; indeed, some of the items refer to transactions

or responsibilities in respect of which either lawyers, architects, or some other class of professional men are likely, as a rule, to be responsible.

It may be remembered that Adam Smith has insisted that the "division of labour," or the "division of employments" as Thorold Rogers prefers to call it, is a dominant factor in the progress of human societies, and it is well known that the "division of employments," or a functional distribution of duties in modern terminology, is the peculiar characteristic in an organization framed to meet the requirements of modern scientific management. There are strict limitations, however, to the extent to which the "division of employments" can be carried; indeed, such a distribution of duties can only be applied in its fullest extent to the functions of and to the subdivision of work among the very subordinate classes of labour, and perhaps to a part of the purely clerical staff in a modern commercial or industrial undertaking. So far as the higher positions in the hierarchical ladder of the staff and the large body of skilled workmen of a complex commercial or industrial enterprise are concerned, no such "division of employments" or "separation of functions" is possible as will provide that any one of the six groups of operations of an undertaking (see Appendix I), referred to earlier, can be assigned for treatment to a separate individual or a class of individuals in an organization in such a way that the individual or class of individuals shall not be concerned in the performance of his or its duties with any of the transactions or responsibilities falling under the remaining five groups or functions. Any order issued by a board of directors or the management of an undertaking with the object of securing any such "division of employments" or "separation of functions" would completely fail in its purpose; an endeavour on the part of the higher officials in an organization to execute such an order would be to attempt the impossible in the case of a small as of a large undertaking. To-day, even in the organization of the largest undertakings, the division of responsibilities is so arranged, and unavoidably so arranged, that every member of the controlling staff must, in the case of an enterprise of either a simple or a complex kind, concern himself with, whether he holds a superior or a subordinate position, at least three of the six groups of transactions or functions; and, in the case of industrial enterprises possessing highly specialized technical branches, as a rule with not less than four of these groups or functions.

It has to be borne in mind that whilst "administration" comprises one of the six functions of an enterprise, administration really also comes into play in every part and in every operation of each of the remaining five functions, and, indeed, throughout the entire undertaking or enterprise; i.e. "administration" occupies a position in relation to every undertaking analogous to that of æther in relation to the universe; that is to say, it is all pervading. Administration is not, as some imagine, an exclusive privilege or even a personal quality in the nature of instinct; it is really a function which, like all essential functions, comes into play between the head and the members corporate of an organization, much in the same manner as human volition operates between the brain and the physical members of the human frame, whereby the latter are caused to exert their latent powers to accomplish some desired purpose.

The very important part administration plays in promoting success in the conduct and operations of undertakings of every kind is widely recognized; and therefore some knowledge of the principles involved in the science and art of administration is essential to everyone forming a link in the chain of organization of commercial and industrial undertakings.

### Qualifications Needed by Engineers Associated with the Conduct of Industrial Enterprises.

It will readily be understood that each of the groups or essential functions into which the several items or transactions of an undertaking or enterprise fall requires a corresponding talent, faculty, or capacity in the person charged with the exercise or execution of the duties connected with or forming part of any particular one of the six functions; therefore there must be six faculties in all, and they may be conveniently identified by being referred to as the financial, the commercial, the technical, that of custodianship, that of book-keeping, and the administrative.

Naturally, the extent to which duties falling within the scope of each of the six functions form part of the responsibilities which devolve upon those holding each of the various offices and positions in existing undertakings and enterprises of a similar kind varies enormously. Now, a general knowledge of the nature of the duties that have to be undertaken by the various classes of employés comprised in an organization is of considerable importance, since it is in relation to these duties that the appropriate faculties, developed in degrees sufficient to meet the needs of a modern undertaking or enterprise, ought to be found in each class or category of employés. The qualifications needed in any particular employé or official in an undertaking necessarily consist in the possession by him or her of some share of some or of all the six faculties referred to above, more or less of each according to the relative importance of the transactions in the several functions in respect whereof he or she may be responsible. Consequently, the nature and extent of the several faculties that are needed by particular classes of employés or officials in an organization command attention, for it is in relation to these considerations that the schemes for the specialized education and training of those intended for careers in the commercial and industrial spheres of national life should, in the author's opinion, be devised. For the foregoing reasons an attempt has been made by the author, in consultation with those well qualified to advise, to estimate approximately the nature of the qualifications, measured in relation to the six faculties referred to earlier, needed by certain officials in two engineering undertakings of different types; the information in question is tabulated in Appendix II. The figures in the Table (Appendix II) bring into prominence the fact—one fully appreciated by many engineers—that the technical faculty, important, and

even essential, as it is in the engineer, by no means constitutes the qualification of the highest importance in those who reach the higher ranks of the engineering profession. It is evident, then, that in many positions which an engineer must occupy, a knowledge of the principles involved in the commercial and administrative side of his work is equally as important to him as is a knowledge of the principles upon which the purely technical side is based. In some cases the administrative faculty has, indeed, in an engineer a higher relative value than has the technical faculty (see Appendix II); further, it will be observed that the engineer must in many positions possess to some extent all six faculties.

Incidentally, it may be remarked that even in the case of the foreman the possession of the technical faculty alone is insufficient, very highly developed though it may be; he also must have developed in him faculties of other kinds—true to a limited extent only—if he is to fill his position with credit to himself and economy to the undertaking in which he is employed.

It is recognized that the method adopted in Appendix II of showing the qualifications under the different faculties in percentages has the disadvantage that the holders of the various positions enumerated all appear to possess, or need, an equal total capacity, whereas, of course, the 100 per cent of the foreman's total capacity is as a rule something vastly different from the 100 per cent of the capacity of those in the grades higher than his own. In the absence of an absolute standard whereby to measure human capacity, and of a means to determine with exactitude the comparative values of the different faculties existing, or needed, in any particular position, the record must unfortunately to this extent appear in a misleading form. It will readily be understood that under any given set of circumstances it is quite possible that, for example, the 45 per cent of the assistant power engineer's technical faculty may be equal or even superior to the $82\frac{1}{2}$ per cent of the charge shift engineer's technical faculty (see Appendix II).

The information tabulated in Appendix II also illustrates the fact, widely recognized in practice in some countries, that in the same way that those responsible for the highly technical work of an undertaking must possess some measure of administrative talent, or knowledge, successfully to handle the problems falling within their proper sphere, so must those who are responsible for the management aspect of modern commercial or industrial undertakings possess some measure of technical knowledge to enable them to exercise their full responsibilities with efficiency and skill.

There is perhaps no more convincing method of bringing about an appreciation of the importance of a matter or thing than by stating its value in some monetary standard. Unfortunately, for reasons similar to those already stated earlier in the paper, it is impossible to supply anything in the nature of precise information concerning the market values in £ s. d. of each of the six faculties to which references have been made. Among the many difficulties met with in this matter, not the least of them lies in the fact that there is no fixed standard of remuneration in connection with positions of a similar order of importance in undertakings and enterprises concerned with almost identical transactions and responsibilities: the State, municipal corporations and public companies each have set up their own standards of remuneration.

The question of the relative values of the several faculties possesses considerable interest from the point of view of the economics of commerce and industry. For this reason, diagrams have been prepared in relation to one of the undertakings concerning which particulars are given in Appendix II. In these diagrams (see Appendix III) the relative salaries and wages of the employés and officials mentioned have been plotted in combination with the estimated personal qualifications needed for the performance of the duties of the positions indicated: the verticals are divided so as to correspond with the percentage figures contained in Appendix II, whilst the horizontals have been drawn proportionate in length to the salaries and wages appertaining to the several positions in the organization. Although it is not possible to show in these diagrams the actual market values of each of the six faculties, either in relation to an absolute standard or relatively to one another, one deduction can safely be made from an inspection of the figures drawn, namely, the higher the ratio of the administrative faculty needed in any particular position or grade, the greater as a rule is the remuneration attached to that position or grade.

### Modifications Recommended in the Present Scheme of Education for Engineering Students.

The importance of the commercial and administrative aspects of the work for which a modern engineer is responsible stands out conspicuously in the Table given in Appendix II; logically then, instruction in the appropriate subjects dealing with the commercial and administrative problems with which the engineer is confronted almost daily should find a place in the curriculum of every engineering course in the schools and colleges of this country. Consequently, the author suggests that steps should be taken to revise without delay the curricula of the engineering courses in question, in order that a wider scope should be provided in the instruction given therein, so that the engineer, on entering upon the active pursuit of his career, may be better equipped than at present properly and efficiently to perform his professional duties from the administrative and commercial points of view as well as the technical.

In making this suggestion the author has not lost sight of the fact that some objections, at least, will be raised to the proposal to widen the scope of instruction given to engineering students by the inclusion therein of commercial and administrative subjects. It may be urged, for instance:—

(1) That no time can be allotted in the curricula of the present engineering courses in order to provide for the instruction in subjects additional to those connected with the technology of the branch of engineering in which a student proposes to specialize, owing to the limited time available to cover the range of

instruction in the technical subjects composing the present courses ; or

(2) That commercial and administrative subjects cannot be taught by lectures, the knowledge connected therewith being such that it can only be acquired in the hard school of experience ; or

(3) That commercial and administrative subjects are proper matters for treatment in graduate lectures, and should therefore be so dealt with ; or

(4) That the engineer's employer is the best-qualified person to impart instruction to him in commercial and administrative subjects, and consequently schools and colleges should deliberately abstain from dealing therewith as being outside the scope of their responsibilities as teaching institutions.

Human nature is exceedingly conservative, and no more so than in the case of those connected with the teaching profession. With rare exceptions a professor is a slave to his own course and quite naturally magnifies its importance. In consequence, the question of the immediate usefulness of the young engineer to his employer at the beginning of his career, and the question of the engineer's qualifications from the point of view of his ultimate earning capacity, are too often lost sight of by those responsible for framing the engineering courses of instruction and for deciding upon the scope of the education to be provided for engineering students.

Now, it is needless to say that each and every one of the above objections, and others similar thereto not formulated above, can be met and disposed of: these objections do not constitute a sufficient argument for the retention of the present schemes provided for the education and training of engineering students. For instance, the matter of finding time for the provision of the necessary preliminary instruction in commercial and administrative subjects is solely a question of willingness to view the various aspects of the engineer's responsibilities and work in their true perspective. A part of what is taught an engineering student during the college course under existing conditions equips him with knowledge that he is never likely to be called upon to put into practice, however useful it may be in the abstract as a part of his specialized information. Other parts of the instruction given to the engineering student impart knowledge of a kind that the engineer does not, as a rule, require to apply in dealing with the problems coming before him in the first days of his active career. The designing of particular types of engineering machinery and plant, for example, has become so highly specialized to-day that a very few engineers alone are in any country afforded an opportunity of putting their talent for design to a practical test; yet, much of an engineering student's time is taken up in learning the details of these specialized branches of an engineer's work. It is inconceivable, therefore, that under these circumstances any harmful results could arise, or that an engineer's usefulness on the technical side of his qualifications could be lowered, by limiting to a small extent the scope of the instruction in those branches of technology which are concerned with highly specialized types of machinery and apparatus, in order to find the time needed for some preliminary instruction in administrative and commercial subjects, that is to say, so that a wider range of subjects may form part of the normal engineering course.

It is recognized that a high standard of knowledge must be maintained on the technical side of the engineer's education in this country, in order that Great Britain may compete on favourable terms in the markets of the world. There should be no difficulty in meeting this situation in the event of the normal course of instruction being modified as proposed above. What really seems to be required is the institution of graduate courses in technology for those possessing rare gifts and a peculiar aptitude for particular classes of highly specialized work, in order to enable such persons to develop their exceptional talents should they so desire.

As regards the second of the objections set out above, those who may be inclined to argue that commercial and administrative subjects cannot be taught by lectures, are invited to examine and consider the means that have been adopted and are now in existence at our universities, the Inns of Court, the London School of Economics, and many other institutions in order to assist young men to qualify themselves for positions connected with the administrative posts in the public corporations or under the Government for the career of a barrister or of a solicitor, etc. The preparatory instruction in all the cases mentioned consists entirely of lectures, and there is no gainsaying that many advantages arise from the adoption of this course. It is an absolute certainty that, if an attempt were to be made by individuals of average ability to face the school of hard experience without some previous preparation and preliminary instruction in the matters connected with the duties of the callings in question, extremely costly mistakes would be made by them at the outset of their careers, whether such career be that of a legal practitioner or that of an administrative official. On the other hand, it stands to reason that, however great may be the mental gifts with which an individual may be endowed, knowledge can be imparted to him in any particular subject in a much shorter time by means of systematic instruction than is the case where a student endeavours to gather it for himself by observation, indeed, by a process of laborious "original research." The question of a student's natural aptitude for acquiring a particular kind of knowledge has of course to be considered ; but in the same way that every schoolboy is, for example, taught a certain amount of mathematics, although he may have no special bent for the subject—and yet manages to acquire a sufficient knowledge thereof to be useful to him for practical purposes—similarly and to the same extent a knowledge of commercial and administrative subjects can be acquired by every engineering student sufficient to enable him to carry on until experience comes to his aid.

After all, it is not mere ability only, or ability combined with experience alone, that is a measure of a man's usefulness ; but this measure consists, as is well known, of other factors also, among which education and training have a prominent place. A small deficiency in respect of one or more of the factors in question can

often be compensated for by superior qualifications in other respects, but a complete absence of knowledge of a kind essentially necessary in any profession or in the conduct of any calling cannot be compensated for; this is where education can help.

As regards the third objection stated above, the argument that instruction in commercial and administrative subjects is a matter exclusively for graduate lectures is really untenable. The absence of the knowledge comprised under these heads causes an engineer to start life improperly equipped for carrying out his duties with efficiency and proper skill; consequently, he is in the early days of his career liable to make mistakes which may prove costly to his employer, and perhaps disastrous to himself.

The foregoing reasons against the postponement of the instruction in commercial and administrative subjects until after the engineering student has graduated also hold good for the purpose of answering the suggestion that it is the engineer's employer who should impart instruction to him under these heads. Moreover, employers are rarely in a position to afford to their employés instruction in commercial and administrative subjects systematically, and therefore even should they be willing to undertake the responsibility, which is extremely doubtful, the knowledge in question could only be imparted imperfectly, and, in consequence, it would be acquired painfully and at the loss of valuable time and money to all concerned.

Objections to the inclusion of commercial and administrative subjects in the curricula of engineering courses are not usually based on the argument that a knowledge of these subjects will not be immediately useful to the engineer in his practice; indeed, it is tacitly admitted by those who raise the objections in question that a large part of the problems with which an engineer has to deal are commercial and administrative in character. The objectors only ask for the instruction to be postponed. Now, one of the most important points requiring consideration in connection with the proposals to postpone instruction in these subjects lies in the fact that there is a tendency on the part of many engineering students to despise the administrative and commercial aspects of engineering work and to consider the same unworthy of their attention. Therein lies a serious danger; for men are unwilling when they have become imbued with a certain theory in any matter to surrender themselves, their conclusions, their prejudices, and preconceived opinions to the guidance of facts and patiently to submit to the results to which these facts lead them. Therefore, unless some instruction is given in the subjects in question during the college course, the sources of information thereon made known and a taste given for the study of this aspect of the engineer's work much valuable time will be lost by an engineer after he has entered upon the practice of his profession before facts can lead him to appreciate the true value of commercial and administrative knowledge and break down any prejudices that may have grown up in his mind on the subject during his college days. Further, by the time an engineer may become convinced of the errors of the views formed on the subject in the days of his studentship, he may have neither the time nor the opportunity of attending graduate lectures to acquire knowledge on essential matters connected with his calling, matters wholly neglected in the college course.

### Scope of the Instruction in Commercial and Administrative Subjects for Engineering Students.

In considering the pros and cons for providing *systematic* instruction in any branch of study, it has always to be borne in mind that "though a study of evidence will not always keep a man right if he happens to be a dolt, it is a miracle if the shrewdest man who has no evidence does not go wrong": *mutatis mutandis*, this statement is true in respect of every kind of acquired knowledge. A case for the inclusion of some preliminary instruction in commercial and administrative subjects in the courses of instruction for engineering students has, it is thought, been conclusively demonstrated by the references given to the actual conditions prevailing in relation to the engineer's work and calling at the present time. The field covered by the commercial and administrative subjects, some knowledge whereof is indispensable to the complete engineer, is so wide that it would naturally be impossible to deal with its whole range during the normal period of the engineering course. It is therefore a matter of paramount importance to arrive at some decision as to the nature and scope of the commercial and administrative subjects in which preliminary instruction should be provided.

Having regard to what has been said earlier as to the nature of an engineer's responsibilities, it is the author's opinion that the preliminary instruction in commercial and administrative subjects in engineering courses should extend at least to the numbers of hours stated below, and should cover the elements of the following subjects:—

| Subjects | Number of Hours' Instruction |
|---|---|
| (*a*) Accountancy and book-keeping | 8 |
| (*b*) Administration and organization | 8 |
| (*c*) Commercial law | 6 |
| (*d*) Depreciation | 2 |
| (*e*) Estimating and writing of specifications | 12 |
| Total number of hours' instruction during course | 36 |

A brief outline is given in Appendix IV of the scope of the preliminary instruction in the above subjects which, it is recommended, should be given. The details of the programmes in each subject must naturally be drawn up by the experts on whom will fall the duty of directing the studies of the students. Narrow as is the scope of the instruction proposed, it will be sufficient, it is thought, to bring home to engineering students the important nature of the commercial and administrative transactions for which they will be responsible in the active pursuit of an engineer's career, and such instruction cannot fail to stimulate the interest of the average student in the wider aspects of the work

connected with his future profession. Once the student's interest is aroused and the sources of information on commercial and administrative subjects are made known to him, there is little doubt that he will apply himself sedulously to the acquisition of further knowledge on these subjects, either by private study or by attending lectures where such are provided. He may well be reminded that an extremely wide range of instruction in commercial and administrative subjects, much of which is of value to him, is already provided in London and at other centres.

It has been suggested to the author that a short list of works dealing with commercial and administrative subjects might prove useful to students and also to engineers; in consequence, such a list has been prepared (see Appendix V)—mention is only made in the list of works which have been in the author's hands—and a note has been made against each work to indicate its standard.

Lest there should be a misconception in the minds of some as to the intentions of the author in advocating that a wider range of instruction should be provided for engineering students than is the case at the present time, he is anxious to make it known that it is far from his mind that engineers should become either expert accountants, or expert lawyers, or even expert financiers: his sole object in proposing the wider range of instruction is to secure that the average engineer shall be in a better position than at present to appreciate the nature of the pitfalls that he may encounter in the everyday practice of his profession, so that he may resort, when the occasion should require, to suitable measures betimes in order to protect himself, as also the interests of his employer.

### Practical Training. "Co-operative Courses."

The question of the education and training of the engineering student on the technical side has been so fully discussed in recent years that there is very little that is left unsaid on the broad aspects of the subject. It must not be implied, however, from these remarks that the present system of instruction, as normally provided, is perfect; on the contrary, the system has the disadvantage that students must, to a great extent, in many cases study the theory and the practice of engineering separately. Unquestionably, the ideal method of teaching engineering would be always to give the instruction in the practice and the theory simultaneously. An attempt to provide such a solution of the problem has been made in the United States of America in connection with the so-called "co-operative system." Under this system the courses are so arranged that the students spend, first, one week at the works of a manufacturing undertaking, and the next week in the college, this weekly alternation of practical and theoretical work being kept up during the whole period of the engineering course. It will be observed from the foregoing description that the "co-operative system" is but a highly developed form of the "sandwich system" introduced some years ago in this country. However, whereas in the former system not only are the alternating periods during which instruction in practice and theory is continuously given much shorter than in the latter system, but the order of dealing with these two aspects of engineering education is also inverted. Consequently, the student, under the "co-operative system," first studies the practical problems in a workshop and is subsequently taught in college the principles that are involved in the solution of the problems arising from week to week in the workshop; that is to say, the theoretical instruction is planned with a view to helping the student to accomplish his practical task more quickly and efficiently, and at the same time with a more perfect understanding. The cost of the "co-operative system" may be comparatively high; however, the education and training provided under this system can be made so broad, and adds so much to the value and completeness of the student's knowledge of both the practice and the theory of engineering, that it appears to be desirable, certainly in the case of the engineering schools and colleges situated in the great industrial centres, that a very considerable effort should be made to introduce "co-operative courses" into this country.

Fortunately, it is widely recognized in this country to-day that the engineer's education cannot be complete without workshop experience, and, indeed, that in many branches of engineering systematic practical training in the workshop is as indispensable to the student as the regular instruction in the engineering subjects given in schools and colleges. For this reason, the important consideration in connection with the education and training of our engineers is that workshop experience shall be within the reach of all young men, rich or poor, intending to enter the engineering profession. Some manufacturing firms have adopted a policy, a very wise and patriotic one the author ventures to say, of receiving as pupils young men, who have been suitably educated for the engineering profession, into their workshops without the payment of a premium. These firms provide systematic courses of training, under careful and strict supervision, in their workshops for these pupils. They properly reserve the right to dismiss any pupil who either lacks interest in his work or does not make suitable progress; but no dismissal takes place until the offending pupil has been duly warned and has, in consequence, been given an opportunity to mend his ways. This is as it should be. Needless to say, if the policy of receiving pupils without the payment of premiums by them were to be adopted universally by all manufacturing firms, large and small, throughout the British Isles, not only would it be of immense benefit to engineering students individually, and as a class, but it would also prove of incalculable advantage to British industry. It would naturally be necessary to provide in each case some scheme of systematic instruction under proper supervision; and to make the system work satisfactorily each firm should naturally retain the right to dismiss "wasters." It is in no one's interest that those who are incapable of learning, or unwilling to do so, should continue to fill up bench space in the fields of production, when there are so many men with talent and a natural

aptitude for technical work anxious and willing to gain experience in order to qualify for commissions in Britain's industrial army.

It is naturally not possible to prescribe here precisely the nature of the workshop instruction that should be given; this is a matter which must depend to a large extent on the character of the activities of each particular firm and of the equipment in its workshops.

### General Education.

There is a consensus of opinion on the subject of an engineer's general education; it is believed that the necessity for the standard of this education being a high one is universally admitted, and therefore no great changes of importance are needed in the present arrangements in relation thereto. The ideal arrangement would no doubt be, as in the case of at least one of the universities in the United States of America, to insist that every engineering student should obtain an Arts degree before he is allowed to proceed to his Engineering degree. However, it is recognized that such a scheme is outside the range of practical politics in this country. Nevertheless, bearing in mind that the saying of the ancient sage, that men should keep on learning as long as they live, is of the widest application and as true to-day as ever it was, engineering students must, whilst studying technology, be encouraged to improve their general education by widening their knowledge of the world and its affairs and by the study of foreign languages. Finally, it cannot be too often and too strongly impressed upon the engineering student that one of the most important qualifications needed in a modern engineer consists in a command of the English language, and a facility to give expression to his thoughts through its medium with clearness, conciseness, and completeness, in speech as well as on paper. Great issues, involving considerable sums of money, sometimes depend, as is well known, upon the choice that is made of particular words and their collocation in a record.

### Recruitment of Leaders of Industry.

It is universally recognized that under the normal conditions of existence, known as a state of peace, there really exists in the commercial relations of States what is a veritable state of perpetual war; the industrial forces of one State are continuously battling against the industrial forces of practically every other State. Under these circumstances it is exceedingly important not only that the leaders of these forces in this country should be men possessing the greatest skill and widest knowledge concerning the undertakings under their immediate command, but also that these undertakings themselves should be properly organized and efficiently administered. It may be taken for granted that, in the same way that the belligerents in the War brought to their aid every artifice, device, and invention which the ingenuity of man could suggest, much in the same way the competitors of Great Britain in the coming economic struggle will take care not to overlook or leave unutilized any weapon of economic warfare likely to prove of advantage to them. Clearly, under these circumstances, what will be wanted in the leaders in commerce and industry will be not only high imaginative power, but also the skill to secure "unity of purpose" in those under them by the direction of their efforts into the most effective channels. In order that the leaders of industry and commerce may be capable of efficiently meeting the demands in these respects likely to be made upon them, a scientific education and technical training of a suitable kind are as essential to them as to the engineer. Great Britain cannot afford, it seems to the author, to be content to go on in the ways of the "good old days." On the principle of "diamond cut diamond" the intellectual equipment and practical experience of Great Britain's leaders of industry must be of a like order to those of the leaders of industry in the countries competing against her in trade. Consequently, if in foreign countries technically trained men have been, and are being, placed in command of foreign industrial divisions and army corps—which actually has been done—our ruling classes owe it to the British people that those who in the future are to succeed to the command of Britain's industrial divisions and army corps shall invariably be as well qualified and as efficient, in every sense, as those against whom they must pit their skill, knowledge, and experience. The situation referred to here emphasizes the importance of the proposal made earlier concerning the introduction of some preliminary instruction in commercial and administrative subjects for engineering students; the need, too, is made manifest for more widespread advanced instruction in these subjects for engineers and others of mature age now engaged in preparing themselves for the coming struggle.

Although not strictly relevant to the subject of this paper, the question as to how best to provide leaders for Great Britain's important industrial enterprises does arise indirectly. The neglect of instruction in science in the schools of the United Kingdom is notorious, and attention has recently been prominently drawn thereto in the Report of Sir J. J. Thomson's Committee on the position of natural science in the educational system of Great Britain (Cd. 9011). The author is of opinion that a mere theoretical knowledge of science alone will do little to provide British industries with the class of men required to conduct technical enterprises with sufficient skill and in the spirit of progressive knowledge: the qualifications that are needed in the leaders of industry consist in a combination of high scientific attainments and proficient technical knowledge. The men possessing the adequate technical knowledge and experience for the purpose in question can alone be found in the ranks of those engaged on the technical sides of the important industrial undertakings of the country; therefore, it is from amongst these men that the selection should in the future be largely made of those who are to take supreme control of Great Britain's technical enterprises, if, indeed, the administrative and commercial faculties in them are developed to a requisite degree to qualify them for undertaking the wide responsibilities which must fall in the coming era on the shoulders of the leaders of industry throughout the world.

### Conclusion.

The question of the education and training of the engineer is closely associated with that of his status. It is hardly necessary to point out that the value of the engineer's special education and training are largely discounted, so long as doubt exists in the public mind as to the status of the general body of members of the engineering profession. Under present circumstances anyone may, without offending against the laws of the land, hold himself out to be an engineer, although he may never have made any study of engineering subjects, and, indeed, without being in any way qualified by reason of having gained practical experience of engineering work. Such a person, of course, runs the risk of an action for negligence being brought against him, and of being mulct in damages in the event of acts of incapacity and of incompetence being proved against him in relation to work for which he may have made himself responsible as an engineer: such a risk, however, will be readily run by those who have nothing to lose either in reputation or in money. Unqualified practitioners in engineering have brought discredit on the profession in the past and will continue to do so until steps are taken to put a stop to their activities. In view of the recognized importance of the engineer's calling, of the wide nature of his functions in relation to the expenditure of vast sums of the people's money, public as well as private, and of the risks and dangers to life and property incurred in the event of his administrative and technical duties being unskilfully performed by him, the time seems unquestionably to have arrived for statutory provision to be made to put some check on the freedom with which the title "engineer" is appropriated by those who are wholly unqualified to practice as such, for the establishment of a register of duly qualified practitioners, and for the constitution of an authority to regulate all matters connected with the control of the profession from the point of view of education and training as also discipline. The need for the statutory control of the engineering profession is, at the present day, equally as great as that for the control already existing in relation to the medical and the solicitor's professions. The author is of opinion that the constitution of a General Engineering Council, possessing statutory powers analogous to those of the General Medical Council, would not only be of benefit to the engineering profession but also be of advantage to the public at large.

Questions relating to the status of the engineer and to his education and training are not merely matters of domestic concern to the engineering profession, or to one or other of the technical institutions in which the interests of engineers centre; on the contrary, these questions are of the highest national importance, being connected, as they are, with the conditions under which a meritorious section of the British community exercise their calling—a calling with which, as previously explained, the industrial progress of Great Britain and the material prosperity of the British people are closely bound up. It behoves the leaders of the British nation, then, to concern themselves actively with matters affecting the engineering profession and to take steps to place it on a basis that will best serve the interests of the State.

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## APPENDIX I.

### Items and Transactions Comprised in the six Functions of an Enterprise or Undertaking.

*Financial Function.*

Raising of capital—Loans—Debentures—Mortgages.
Trading capital.
Reserve funds—Investments.
Goodwill.
Assets, e.g.—Stocks of raw materials and stores.
Stocks of manufactured goods.
Bills receivable.
Cash balances.
Liabilities, e.g.—Salaries and wages.
Bills payable.
Miscellaneous accounts payable.
Depreciation—Sinking fund.
Deposits—Advances—Overdrafts.
Premiums—Discounts—Interest.
Banking transactions.
Profits—Dividends.

*Commercial Function.*

Study and securing of markets—Intelligence department—Advertising.
Buying—Selling—Auctions.
Tenders—Contracts—Hire-purchase and other agreements.
Fixing of sale prices of goods and manufactures.
Clients—their importance—their solvency.
Counting-house matters generally.

*Technical Function.* (This function includes all transactions in relation to which highly specialized knowledge is required.)

Patents—Licences—Royalties.
Real estate—Leases—Location of factories.
Plant—Stores—Specifications—Designs.
Working of a plant or business—Manufacture—Production.
New works—Remodelling or extension of existing works or business.
Maintenance of plant, fixtures, and stores.
Fatigue study—Motion study.
Piece rates—Standard methods.
Cost accounting—Estimating.

*Custodianship Function.*

Protection of physical property, of rights and interests.
Precautions against fraud, theft and loss—Measures to avoid accidents.
Litigation—Conciliation and arbitration—Industrial Councils.

Perambulation or beating of bounds.
Insurances—Watchmen.
Sanitary services (hygiene).

*Book-keeping Function.*

Balance sheets and revenue accounts—Profit and loss account.
Bank accounts—Cash accounts—Petty cash accounts—Trading accounts.
Methods of record—Statistics.
Preparation for audit.

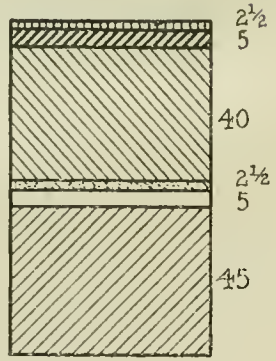
*Administrative Function.*

Business policy—Preparation of programmes of work.
Direction of the business—Efficiency methods of management.
Co-ordination of effort—Staff conferences—Supervision.
Staff organizations—Engagement of staff—Conditions of service.
Promotions—Rates of salaries and wages—Profit-sharing—Bonuses.
Sick-pay—Allowances—Pensions.
Organization of control and responsibility.
Study of labour legislation and labour problems generally.
Welfare work.

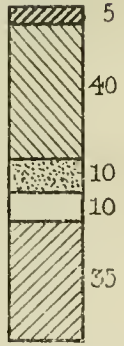
## APPENDIX II.

### Estimate of Qualifications Needed by Certain Grades of Officials in Two Types of Engineering Undertakings.

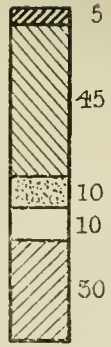
| Grade | Faculties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Financial | Commercial | Technical | Custodian-ship | Book-keeping | Adminis-trative | Total |
| *Tramway Undertaking.* | % | % | % | % | % | % | % |
| General manager | 10 | 5 | 25 | 5 | 5 | 50 | 100 |
| Chief engineer | 2½ | 5 | 40 | 2½ | 5 | 45 | 100 |
| Power station engineer | — | 5 | 40 | 10 | 10 | 35 | 100 |
| Assistant power station engineer | — | 5 | 45 | 10 | 10 | 30 | 100 |
| Charge shift engineer | — | 2½ | 82½ | 5 | 5 | 5 | 100 |
| Foreman | — | — | 85 | 5 | 2 | 8 | 100 |
| Traffic manager | 5 | 10 | 10 | 15 | 15 | 45 | 100 |
| Development superintendent | 5 | 35 | 5 | — | 30 | 25 | 100 |
| Operation superintendent | 5 | 15 | 10 | 25 | 10 | 35 | 100 |
| Divisional traffic superintendent | 5 | 15 | 10 | 25 | 10 | 35 | 100 |
| Permanent way engineer | 5 | 10 | 35 | 10 | 5 | 35 | 100 |
| Assistant permanent way engineer | 5 | 5 | 30 | 20 | 5 | 35 | 100 |
| Foreman | — | 5 | 50 | 20 | — | 25 | 100 |
| *Manufacturing Company.* | | | | | | | |
| Managing director | 40 | 15 | 5 | — | 5 | 35 | 100 |
| Commercial manager | 20 | 35 | 15 | — | 5 | 25 | 100 |
| Manager of traction department | — | 40 | 20 | 10 | 5 | 25 | 100 |
| Manager of central station department | — | 40 | 20 | 10 | 5 | 25 | 100 |
| Manager of supplies department | — | 45 | 15 | 10 | 5 | 25 | 100 |
| Manager of lamp department | — | 45 | 15 | 10 | 5 | 25 | 100 |
| Chief engineer | 5 | 10 | 40 | 5 | 5 | 35 | 100 |
| Works manager | — | 15 | 35 | 10 | 5 | 35 | 100 |
| Foreman | — | — | 65 | 10 | 5 | 20 | 100 |
| Inspector | — | — | 70 | 10 | 5 | 15 | 100 |



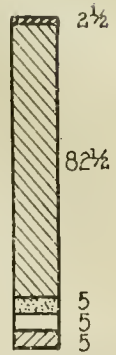

Chief Engineer



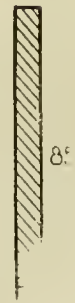

Power Station Engineer



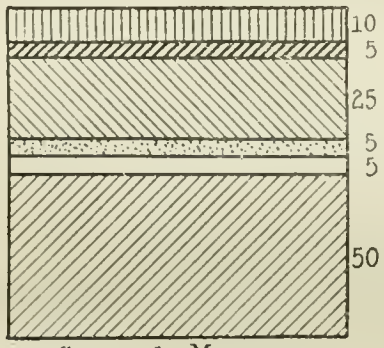

Asst: Power Stn Engineer



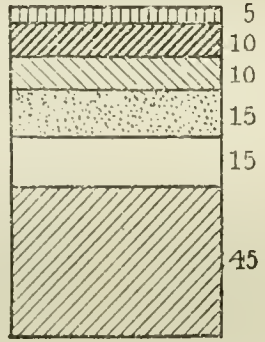

Charge Shift Engineer




Fo.



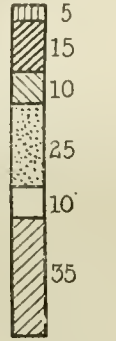

General Manager



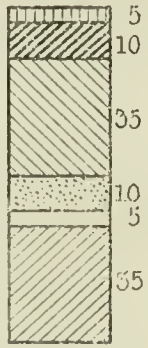

Traffic Manager

Development Supt.

Operation Supt.




Div: Traffic Supt.




Permanent Way Engineer

Asst. Permt. Way Engineer

Foreman

## Explanatory Note

*Financial Faculty* =

*Commercial Faculty* =

*Technical Faculty* =

*Custodianship Faculty* =

*Book-keeping Faculty* =

*Administrative Faculty* =

## APPENDIX IV.

### Scope of the Instruction in Administrative and Commerical Subjects Proposed to be Included in the Normal Engineering Course.

*Accountancy and Book-keeping.*

Definitions and explanations of terms: "Dr." and "Cr."; assets and liabilities; "single entry" and "double entry"; etc.

Uses of various account books: day-book; sales-book; invoice-book; journal; cash-book; ledger; costs book; etc.

The principle of exchanges: book-keeping, a record of exchanges; pecuniary rights and obligations; classification of exchanges; results of exchanges.

Principle of "Dr." and "Cr." accounts: methods of book-keeping.

The principle of the classification of accounts.

Principle of ledger entries—Principles of "proving."

Principle of chronological or preparatory record.

The principle of "balancing" and "proving" the ledger.

Cost accounting: time cards; labour cost; material costs.

*Administration and Organization.*

Definitions and explanations of terms: administration; management; organization.

Problems of commercial and industrial enterprises: the six functions in an enterprise.

Methods of administration: the bureau system; the college or board system; types of college or board system; characteristics of the various systems.

Bases of administration: familiarity with methods; appreciation of uses and limiting capacities of materials and machines; the art of handling men.

Principles of administration: a steadfast policy; unity of purpose; division of labour; centralization of control; decentralization of execution; the "chain of command"; "liaison" within the organization; support of subordinate authority; maintenance of discipline; encouragement of initiative; responsibility with accountability; permanency of employment; equitable treatment of employés; regard for social welfare of employés.

Constituents of administration: foresight; direction; organization; co-ordination; control.

Tools of administration: "standing" instructions; the bulletin or circular; staff conferences; the personal interview; correspondence; the telegraph and telephone; card index and filing systems; clerical and accounting labour-saving devices; time-recording and cash-registering machines; directories and other standard works of reference.

Efficiency of administration: the personality of the chief and the sub-chiefs; skill and loyalty of employés; utilization of diagrams, records, statistics, accounts, etc.

Principles of organization: the fundamental rules.

Types of organization: early models; the "military" or territorial model; the functional model; examples of industrial organizations.

Divisions and sub-divisions in staff organization.

*Commerical Law.*

General view of the law of contract: definition of contract; formation of contract; capacity of parties to a contract; form and consideration; legality and possibility; mistake, misrepresentation and fraud; rights and obligation; discharge of contract.

Commercial relations between persons: agency; partnership; companies.

Particular commercial contracts: sale of goods; bills of exchange, notes and cheques; carriage; insurance; suretyship and guarantee.

Miscellaneous matters: securities; shipping; patents, trade marks and copyright.

Insolvency: bankruptcy practice.

Arbitration: the submission; appointment, authority, duties and responsibilities of arbitrator; the award.

*Depreciation.*

Definition of term.

Engineering aspects: physical decay; obsolescence; inadequacy; tenure; effect of legislation; estimates of "lives" of machinery and plant; unforeseen circumstances.

Accountancy aspect: methods of financial treatment of depreciation fund.

*Estimating and Writing Specifications.*

Technical preparation of estimates: nomenclature of machines and plant details; materials; calculations of quantities; estimating analysis.

Commercial aspect of estimates: meaning of a cost estimate; approximate estimates; estimates based on manufacturers' catalogues; detailed estimates based on plans and drawings; basis rates for labour; sources of information of wages rates in the United Kingdom and in foreign countries; basis rates for raw materials; sources of information relating to prices of materials; private prime cost-book; standard price lists; determining establishment charges, indirect or general expenses and departmental costs; use of freight tables; making up an estimate.

Classes of specifications; objects and uses of a specification; essential parts; arrangement of clauses; lettering and numbering specification and drawings; statutory provision as to specification in contracts of public authorities (Public Health Act, 1875, Sec. 174); specifications of British Engineering Standards Committee.

Engineer's responsibilities in relation to execution of work detailed in specification; consequence of negligence in drawing a specification; fraud in relation to a specification; necessity for use of precise and unambiguous language in a specification.

## APPENDIX V.

### List of Some Works on Administrative and Commercial Subjects likely to be Useful to Engineering Students and to the Engineer.

*Accountancy, Banking and Book-keeping.*

"Advanced Accounts." By R. N. Carter. (Advanced.)
"Company Accounts." By A. Coles. (Advanced.)
"Cost Accounts in Principle and Practice." By A. C. Ridgway. (Advanced.)
"Manual of Book-keeping." By J. Thornton. (Advanced.)
"Balance Sheets: How to Read and Understand them." By P. Tovey. (Elementary.)
"The Elements of Banking." By J. P. Gandy. (Elementary.)

*Administration and Organization.*

"Commercial Encyclopedia and Dictionary of Business." By J. A. Slater. (Advanced.)
"Commercial Management of Engineering Works." By F. G. Burton. (Advanced.)
"Counting House and Factory Organization." By J. G. Williamson. (Advanced.)
"The Exporter's Handbook and Glossary." By F. M. Dudeney. (Advanced.)
"Factory Administrations and Accounts." By E. T. Elbourne. (Advanced.)
"Municipal Office Organization and Management." By W. Bateson. (Advanced.)
"Office Organization and Management." By L. R. Dicksee. (Advanced.)
"The Elements of Political Economy." By H. Hall. (Elementary.)
"The Principles of Business." By J. Stephenson. (Elementary.)
"The Principles and Practice of Commerce." By J. Stephenson. (Elementary.)
"The Theory and Practice of Commerce." By F. Heelis. (Elementary.)

*Commercial and Engineering Law.*

"Hudson on Building Contracts." (Advanced.)
"The Law affecting Engineers." By W. Valentine Ball. (Advanced.)
"The Law of Carriage." By J. E. R. Stephens. (Advanced.)
"Mercantile Law." By J. A. Slater. (Advanced.)
"Commercial Law of England." By J. A. Slater. (Elementary.)
"The Elements of Insurance." By J. A. Eke. (Elementary.)
"The Law relating to Engineering." By L. W. J. Costello. (Elementary.)

*Depreciation.*

"Depreciation and Wasting Assets." By P. D. Leake. (Advanced.)

*Estimating and Writing of Specifications.*

"Engineering Contracts and Specifications." By J. B. Johnson. (Advanced.)
"Approximate Estimates." By T. E. Coleman. (Elementary.)
"Case and Freight Costs." By A. W. E. Crosfield. (Elementary.)
"The Elements of Engineering Estimating." By A. Suggate. (Elementary.)
"Engineering Estimates and Cost Accounts." By F. G. Burton. (Elementary.)
"Engineers' Costs." By D. Smith and P. C. N. Pickworth. (Elementary.)

## Discussion before The Institution, 13 February, 1919.

**Mr. A. P. M. Fleming**: I agree very heartily—and I think most people will do so—with the author in his plea for the inclusion, in the training of an engineer, of instruction dealing with the administrative and organizing sides of his work. It is, however, unwise to adopt and apply the practice of other countries and other peoples too literally, without fully considering the differences between the national characteristics of those peoples and ourselves. This applies particularly in attempting to follow the Continental practice, especially German practice. With reference to the manner in which this instruction will be given, it is scarcely possible to restrict or limit the technical instruction already given in universities and colleges, for this must be the central point around which the training of an engineer hinges. There is a praiseworthy tendency for the universities to raise the standard of their intermediate science examinations, and to admit students at this stage. Three years' training subsequent to this affords opportunities for the inclusion of the special subjects referred to by the author. At the same time there is no reason why the boy of 17 or 18 should not go to a university with a sound knowledge of some of the principles of the subjects for which the author pleads, such for instance as book-keeping. It is also possible to acquire much of this instruction in post-graduate courses, and at this period the instruction is particularly easily grasped on account of the fact that the young engineer, having commenced practical work, is able to see what direction his future career will take and to appreciate his own particular needs. Such courses, moreover, may be taken by young men who have risen from the shops and who have not received university training. Care must be taken that all facilities required by these men are provided. I can scarcely agree with the paragraph on page 227, headed "Scope of the Engineer's Responsibilities." For many years past I have been directly interested in the staffing of a large industrial works, and I am more and more convinced of the desirability of employing the broad-minded man who has learned to think logically and who can make use of and turn to account in a new direction all the information, knowledge, and experience that come his way. I

should always prefer such a man to one who is a specialist, or who has specialized knowledge of one or more subjects, even though he may be more brilliant. The former can rapidly adapt himself to a new situation; the latter lacks frequently that broad basis which is necessary to do this. I am unable to understand the use of the term "Faculty," particularly in connection with the illustrations at the end of the paper. Perhaps I misunderstand the author, but it appears to me that faculty is innate and capable of development, otherwise promotion becomes impossible. If, say, a foreman is promoted to new responsibilities and ultimately becomes general manager, his faculties do not change, but those that he has are developed by experience. I interpret the diagrams as meaning that in any particular job the stated proportions of a man's time and energy are directed to the sections indicated. I think, therefore, that we may make a mistake in depending too much on this particular instruction, rather than in endeavouring to develop men in an all-round way. I regret that the author has not paid more attention to practical training in works, which has been dealt with rather briefly. There is great misconception about this training, the real function of which is not to provide specialized engineering experience, but to bring a man into contact with the widely varying activities of the engineering profession so that he may develop his particular bent. The author considers it patriotic for firms to take young men at their works without payment of a premium. This is really nothing of the kind. It is merely common-sense business policy; for any undertaking which desires to train its future staff is committing commercial suicide if it restricts entry into its works to those men who have financial resources. There is a growing tendency not only to ask no premium, but to pay such apprentices a rate almost sufficient for maintenance. In Appendix I the author includes fatigue study under the Technical Function. It appears to me that this should fall under the Administrative Function. There is no reference to research. This should certainly come under one of the functions mentioned or be tabulated as a separate function, as also would education of juveniles and of adult workmen. Finally, I should like to call the attention of the author to the action of the University of Manchester in co-operating with several local firms in appointing a Director of Industrial Administration. A number of public lectures have already been given in connection with this new department on subjects closely related to the matters with which the author has dealt. Ultimately it will crystallize into a proper day course, at which young men can receive instruction in the science of industrial administration.

**Mr. R. S. Allen:** The paper undoubtedly makes out a case for the broader training of the engineer, but, as Mr. Fleming has stated, the difficulty is to find time for the extra instruction. The choice before nine out of ten students (since they do not know beforehand in what direction their energies will be employed) in regard to their profession is so immense that they must take a very general course of training. The tenth man, however, may have a position ready for him, and he it is who really requires the more special training. I consider the college course to be of value, not so much for the many facts taught, but as the training ground for the reception of future knowledge. Many of the things we learn we forget, but the intensive culture of the brain enables one to pick up things more quickly, so that when a student reaches a position of responsibility, he gathers from his surroundings the necessities of the position. The period of an engineer's training is some 5 years, and if he commences at 18 he is 23 before he is independent of his parents. Any lengthening of the training, therefore, is not desirable from the point of view that a man should be earning his own living at that age. On the other hand, if the additional training which the author advocates could be done in 36 hours—I doubt very much whether one can learn a great deal in that period—that extra time ought easily to be allowed for. Generally speaking, the college yearly course is about 1,000 hours, and 36 hours represents only about $3\frac{1}{2}$ per cent. I agree with Mr. Fleming that knowledge of book-keeping and accountancy could and ought to be taught at school. It is a part of mathematics in its higher grade, and being taught at school the whole of the student's time afterwards could be devoted to technical matters. The training of an administrator is hardly a matter which can be done by lectures; it is entirely a matter of experience. The great stronghold of the administrator is tact, and that cannot possible be taught by word of mouth. The figures in Appendix II tabulating percentages for different positions must vary considerably in different categories of the profession. I look upon the 5 per cent technical knowledge allocated to the managing director as altogether too small. A managing director has a considerable number of decisions to make in technical matters and he must be prepared with the necessary knowledge. With regard to the subject of co-operative training in theory and practice at the same time, I foresee much difficulty in maintaining discipline. Where a student is at the works for one week and at the college for the next week, there must be a great waste of time. Broadly speaking, there should be two periods of training:—(1) the workshop, and (2) the college. The order chiefly depends on the boy's character, but the two should be entirely independent. A student entering a works would be there for 2 or 3 years where he has about him machinery which enables him to appreciate questions of design, and otherwise. During the time he is there, he should have instruction from a specially qualified demonstrator whose business it is to keep his brain occupied in continuation of his school training, thus preparing him for the higher technical education of the college course. I am afraid I cannot altogether agree with the author or with Mr. Fleming on the subject of premiums. The training of a mechanic and the training of an engineer are two different things altogether. All other professions pay for their education, and I think it would be a mistake to abolish premiums. A man who wishes to obtain a better education for his son ought to be able to do so by payment, otherwise it might be suggested that all schools both private and public should be nationalized, which would undoubtedly be a mistake.

**Professor W. H. Eccles**: As a whole I think the author does two things: he points out that the colleges have neglected a very important side of the life work of the engineer, and in the second place he advocates that there should be an infusion of new matter into the curriculum in order to remedy the above defect. I support very warmly his proposal, and if we are persuaded by his paper to prepare for the coming competition the service he will have rendered is on a national scale. I think, therefore, that in proposing these reforms he will be met and resisted by some of our national characteristics. For instance, it is one of our national characteristics never to move or to do anything until it is very urgently necessary, in fact until it is almost too late. Another national characteristic is that we like to see a remedy tried first on somebody else. So I think the questions that will arise in ordinary minds are: Is the time ripe for this change in curriculum, and is the change feasible? I am convinced by the arguments in the paper that the time is ripe—foreign competition is going to be very keen in the days to come; and I think the author's scheme is feasible for the reason that we have seen it tried fairly successfully in America and in France. Then, again, I consider it to be a sign of the times, in spite of what Mr. Fleming said—a kind of national sign—that Manchester has moved in this matter already. It is an old boast of Lancashire men that what Lancashire thinks to-day England will think to-morrow. The fact that the Manchester College of Technology has introduced this subject into its programme and seems to be intending to weld it into the engineering courses in some way or other, is an indication that we shall be doing the same thing in London within two or three years. I think that we in London are late in this matter not because we have not got the people competent to deal with the subject—in fact, this subject broadly called "Administration" is taught in London at the polytechnics and particularly, to a degree of great excellence, at the London School of Economics—but because we have not seen the benefit of making this amalgam of the theory of business and the theory of engineering. The machinery of business is not nearly so obvious to the eye as dynamo-electric machinery, and therefore we have not thought of teaching them together. The author in one part of the paper blames the teacher for excess of inertia. I think the inertia of the teacher is due to this feeling of responsibility. He wants to teach principles of value by methods that will train the mind properly at this very flexible age. He emphasizes principles because technical details are by their very nature ephemeral, while principles are eternal. Then, again, he wants to cultivate the understanding of students and to inculcate as much as he can of that very valuable faculty called judgment. I may say that in "judgment" I include the capacity of distinguishing between a sound argument and a false one, the capacity of detecting fallacies. In this connection he wants to teach the habit of what we may call "analysis," the reducing of complicated problems to fundamental principles. The teacher has all these things in mind when he meets any suggestion of a change in curriculum. Of course he hesitates, and people who do not feel that he has all these things in mind accuse him of being a little slow. But I think this subject of administration is reducible to principles; in fact, I think it is a subject that is put on the basis of principle as distinct from technical detail more easily than most other subjects. It is a subject of principles *par excellence*. From the author's syllabus we may see that the word "principles" occurs extremely frequently; it is only the principles of the law of contract that will be taught in any short course, and not the details of the Acts dealing with contracts or the details of Case Law. Therefore I think this subject could with advantage be introduced into our college curriculum, and I intend to do as much as I can in that direction because of the three things I have mentioned, viz. that it is a matter of national urgency; that it is feasible and has been thoroughly tried; and that it is educative.

**Professor E. W. Marchant**: I should like to emphasize what Dr. Eccles has said with reference to the statement in the paper as to the conservatism of professors. I think the author has been much too hard on us. Really the conservatism comes from the other side. The training which the author has laid down as desirable for engineers will, I believe, meet with the approval of nearly all those who are engaged in teaching. I agree also with Dr. Eccles in his suggestion that some of the subjects referred to, such as book-keeping, accountancy, and also much of what is known as administration, are better taught at school. A great deal of what is known as administration, however, cannot be taught at all, in the ordinary sense of the term. As a previous speaker has said, the success of an administrator depends very largely on the tact of the individual. That is a quality which can best be gained by a good general education at a really good school; and although the public schools of this country have had a great deal said against them in regard to the curriculum on which they insist, they have done a tremendous service in bringing out this quality of the individual. I think we shall find that, as a result of so many of our younger men having joined the Army, there will be a great improvement in their capacity as administrators. I must qualify this statement, however, by saying, with all deference to the author, that I do not wish to suggest that the methods adopted in all Army organizations should be carried out in practical engineering. The author has said that the technical qualifications of students in this country are too high; that is, that we specialize too much on technical subjects. I think that is really quite wrong. I do not suggest that all students should be brought to the very highest standard of technical proficiency, which it is necessary they should attain if they go in for such work as design, but I think the standard of technical training which has been reached in a great many cases is far too low. I think it is lamentable that so many of those who are in responsible positions as designers in electrical firms in this country are not English, and I think the colleges will have to look to it to see that their trained technical men can fill such positions in the future. With regard to what the author has called the co-operative system, in which

workshop and educational training are mingled intimately together, it may be a very good system and it may be a practical system in works schools, but I am quite sure that it is quite an unpractical system as regards university students, and speaking generally, at any rate on educational grounds, it would not be satisfactory. The break in the works training and the going from college to the works every week, would mean a very serious interruption in both courses of study. I should like to express the appreciation, which I am sure we all feel, of the last few paragraphs of the paper. I am entirely in favour of the abolition of premiums. I do not think any of the students in electrical engineering who have left Liverpool University have ever paid a premium for their training in a works. I think the principle is wrong. If we want to get the best men into the works I think there ought to be an absolutely free choice, and they can only get that if they take people who cannot afford to pay premiums as well as those who can. In conclusion, I should like to say a word on the question of general education. Public school education is very valuable from one point of view, but it is very bad from another, because there has been an almost entire neglect of the teaching of science in such schools. That is now being remedied. If science teaching can be made a really effective part of school training I am in favour of raising the age of leaving school and of bringing the prospective student to a higher standard of general scientific education before he goes to the university than has been the case in the past. I hope the general tendency will be in that direction, because I am quite sure that the last years at school may be made of very great value. If that is done I think a good deal of what the author has proposed could be carried out in the schools, and I am quite sure that we, in the universities, shall be only too glad to include in our college courses nearly all of the other work that the author recommends.

**Mr. A. P. Trotter**: At one time I was one of the "other persons" on the Board of Studies for electrical engineering in London University, and I objected in those days to the amount of detail which was taught in electrical engineering, such as the designing of switchboards. I think that was wrong, because, as we have just heard, principles being eternal should be taught, but details of design are continually changing and they must be out of date almost before the student leaves the college. I also urged in those days, and at the Educational Conference held by the Institution of Civil Engineers, that there should be some sort of commercial training. I was apprenticed to an old-fashioned firm to whom I paid my 500-guinea premium, and I never learned the remotest idea of costing. Some years afterwards I set up in business on my own account, and burned my fingers badly. My partner, who did not know much about it either, fortunately was fond of figures, and we ultimately arrived at the right principle by common sense. I think where commercial administration, commercial law, depreciation, etc., are taught, the principles of costing should also be included, and it can be done on very broad and general lines. The mistakes that one has seen quite recently in munition work due to ignorance of costing have been very serious. After all, the successful engineer is the man who does for 1s. what any fool can do for 5s. The whole essence of successful engineering is measured by economic results. It is of very great importance that the principles of costing should be taught at school or college, and, if these principles were better known, the working man would have a chance of learning the relation of the wages which he earns to establishment charges, selling expenses, prime cost, turn-over, net profit and dividends, and would not fall into the disastrous blunders which cause so much mischief.

**Mr. D. Murray**: The author invites us to turn for a moment from the machine to the mind at the back of the machine, and to the best equipment of that mind. Nothing is more vital. As the mind is, so will the machine be. The most important of all professions is that of the engineer. He carries on both war and peace; he is the doctor of civilization; he makes and repairs and keeps in order the nerves and arteries and muscles of nations—the telegraph and telephone, the railway, the steam engine. All the powers and energies of social life are due to the work of the engineer. It is therefore surprising that more attention has not been given to such an important subject as the author has brought before us to-night. I do not see how there can be any difference of opinion about the need for broadening the basis of the engineer's education along the lines indicated by the author. The future is for the engineer, and his best weapon will be a high standard of special and general education.

**Professor G. W. O. Howe**: The author has told us that administration is already taught in the colleges of America and on the Continent, and we have also heard from Mr. Fleming that it has recently been adopted to some extent in Manchester. For 15 years or more a course of lectures on workshop accounts has been given to all the third-year engineering students at the City and Guilds Engineering College. The time devoted to the subject is 10 to 12 hours, i.e. less than one-third of the time that the author suggests should be devoted to the subject. The part of the author's proposed syllabus which we cover is that dealing with the principles of book-keeping and workshop accounts. Of course one cannot teach students the principles of costing unless they first have a working knowledge of the fundamental principles of book-keeping, so that the course resolves itself for the first half into principles of book-keeping, and for the second half into workshop accounts. The examination in this subject was on Tuesday last; I have the examination paper here, and to give members an idea of the scope of the course I will read the questions that were set. "(1) Explain the difference between the Trading Account and the Manufacturing Account, and describe briefly how each is made up. (2) Show the Ledger entries for the following transactions:—Jan. 10. Sold goods to Mr. A. for £100 cash. Jan. 11. Sold goods to Mr. B. for £200 on credit. Jan. 12. Bought goods value £150 from Mr. C. on credit. Jan. 13. Paid £300 in wages. Jan. 14. Mr. D. settled his account of £70, being allowed $2\frac{1}{2}$ per cent discount. (3) Into what separate books is the Journal subdivided? Explain the advantages of the subdivision. (4) Explain the

piecework and premium systems of remunerating labour, and discuss their relative merits. (5) What is the Prime Cost of a job? How is it determined? (6) Discuss the question of the proper allowance to be made for depreciation of plant, etc., and explain how this allowance is brought into the Balance Sheet." That examination is set for third-year students, electrical, civil, and mechanical, and I think I can safely say that the course is interesting and useful. I am afrad if any attempt were made to increase the number of hours allotted to the subject one would get into great difficulty. Everybody engaged in teaching engineering students is aware of this great difficulty at present. The syllabus is so crowded. The subject of engineering is developing so rapidly; new fields are continually being added which a student leaving college at the end of his third year is supposed to know. Although one teaches only fundamental principles, subjects like radio-telegraphy bring in quite a new field of fundamental principles which the students have to be taught. On entering the college the students are very little, if any, better equipped than they were 20 years ago; they spend no longer time at college and are supposed to cover a much greater field. I am afraid if the author were given the actual syllabus showing the number of hours devoted to the various subjects and were asked which of those he would sacrifice in order to devote a larger amount of time to the subject of administration, he would find himself in a serious difficulty. What are we going to sacrifice? Surely for electrical work we need a thorough grounding in physical principles. Then there is mathematics; one would hesitate to cut that out to any extent. Electrical engineers must have a very sound grounding in all mechanical engineering principles, and it is very difficult indeed to see what one can cut out in order to be able to devote further time than we do at present to this subject of administration. I am afraid there is a danger of taking the syllabuses of some of the American universities at their face value. The syllabuses look exceedingly comprehensive, but from my knowledge of English and American students I am afraid that it is impossible to get breadth without sacrificing depth. In my opinion it is preferable rather to err in the other direction, i.e. to sacrifice something of the breadth for the sake of depth, and to leave some subjects severely alone if we can only thereby give a student a thorough grounding in the subjects that are left.

**Mr. J. S. Highfield**: As I read this paper, I assume that it has been written with the special object of finding means to assist engineers to secure more important positions in the administration of the works that they erect than they have done in the past. I think the reason why engineers very often fail to take a commanding lead in the conduct of business is partly because of the complexity of their training. The principles of business, relatively speaking, are simple, and, unless a wide outlook is maintained with those simple principles as a sheet anchor, failure in business is bound to result. The education of the engineer is already a complicated matter. He must study in considerable detail, physics, mathematics, and the various subjects that Professor Howe has just referred to, and it is the knowledge of that detail which tends to push out of the engineer's mind the simple principles that must be kept in the forefront if business is to be conducted to a successful end. Therefore, whatever clauses are added to the college curricula, I think they should deal with main broad principles rather than with details. Take, for instance, the detail of book-keeping. It is important, but it can be learned quite quickly by anybody who really wants to know it. It does not, however, interest a great many engineers. It probably will not be necessary for them to learn it, and therefore I think that to try to make that and similar subjects part of the regular training of an engineer would probably be a mistake. Thinking over my old college days, I remember the tendency there was to find that there were too many uninteresting classes and that one did not get enough time for the interesting classes; and the only blank that I remember in the college lectures was a series of simple lectures indicating what a student would do after he left the college and what kind of work he might take up. I think that quite a small number of lectures on that subject by men who had really been in some sort of practice—lectures outside the college curricula altogether—would be of immense use to students. Then if, in addition to that, there were certain extra classes dealing with these many points of business, the student could choose which of those extra classes he would like to attend, and in that way I think they would prove most useful. The author does not refer anywhere in the paper to one faculty which is, I think, more essential than any other in the management of a company or an enterprise requiring a large staff—one speaker referred to it when he used the word "tact." That quality is not one that is easily learned, although no doubt it can be improved; but if there is one thing more than another required by the head of a large business it is the ability to choose a staff and, having chosen it—and many of its members are bound to be second-rate and not all that he expected—to get the best possible work out of it. That is a matter which I do not think can be taught in college. That brings me to another point about which I desire to say a few words. I have been consulted by many men who have been out in France, or serving in the Navy, during the war and who have now come back to this country at the age of, say, 23 up to 28 or 30, many of them having no grounding in any profession, and they ask me what they ought to do. At first sight it is certainly rather a gloomy outlook. I do not know that my point of view is right, but this is what I think. In learning an ordinary profession one has good schooling and then, by the time one is 21 or 22, after going through a college course or works, or both, one has learned the technicalities. From 22 or 23 up to, say, 28 or 30, one is really beginning to learn all about business, and the handling of men and generally dealing with one's equals or superiors. That takes some six or seven years. I contend that the men who have been out at the front have crammed the experience of those six or seven years in ordinary life into a period of three or four years and that, if they apply themselves with the same energy to techni-

cal work for the next two or three years, they will find themselves fully equipped for their work in life at an earlier age than if they had not done all the work they have done for the country during the war.

**Professor F. Bacon:** As one who is concerned in the teaching of engineering subjects, I should like to thank the author for his responsible and constructive criticism of engineering curricula as they existed in this country prior to the war, and for the definite and practical proposals he has brought forward for improving them. In Wales, we are now entering the throes of a very drastic and unproved change in the system and control of teaching and of awarding degrees in technological subjects. In the battles which are raging round this radical form, I am glad to find I can take cover behind the author's authority, both from reactionary academic opinion and from the cross-fire of educational Bolshevism, propounded by unenlightened employers who harbour dangerous illusions respecting the now popular cry of "the application of science to industry." All who have had first-hand experience of the ordeal must deplore the painful struggles and set-backs still enconntered by average young men, and even by particularly able young men, in crossing the chasm which separates their college days from their first responsible positions in industry. My remarks will be confined to the expedients which the author has proposed for bridging this chasm. I think most of us will agree when he attributes the depth, width, and ruggedness of this chasm to the innocence and ignorance of the raw college graduate respecting the commercial and administrative sides, which constitute such an important proportion of the duties connected with the industrial position to which he aspires. The author advances the view that much of this regrettable innocence and ignorance can be dispelled by the simple device of attending suitable lectures. Having no direct experience to guide me, I am inclined to preserve an open mind on this point; but for the purposes of argument, I wish to adopt his optimism. Granted, then, that such lectures can achieve their purpose, why have so few of them? The total time assigned by the author for such subjects is 36 hours, which seems to be only about 1/50th of the total number of organized hours of study comprised in an average college curriculum of three sessions. Now my experience of teaching classes of adolescent engineering students has led me to suspect the efficiency of such small amounts of strange subjects. They make for superficiality and diffusion of effort, and are therefore educationally unsound. Admitting that first-, second-, and third-year courses as at present arranged for engineering students are so overcrowded already that it will even be difficult to fit in 36 hours by the process of pruning down, is there anything really to fear in cutting off a whole branch of the existing tree to make way for such an important and far-reaching innovation as is here proposed? My point is that I am so anxious to afford a genuine opportunity of effectively introducing these lectures on commercial and administrative subjects, that I would be prepared to eliminate from the requirements of the initial degree one whole technical subject in its advanced stages. Another objective, at which I should like to aim at the same time, is that a deserving, but non-mathematically minded, student might have the means really to distinguish himself in commercial and administrative subjects which have not got a mathematical basis but which, nevertheless, are immensely important and helpful in industry. Would it not be advisable, for the purpose of initial degrees, simply to recognize two kinds of engineering degrees, namely, a B.Sc. degree in technical engineering—the accent being on the word "technical" and not at all on any particular branch such as mechanical or electrical, etc.—and a B.A. or B.Sc. degree in business engineering? To secure thoroughness and an early aptitude for specializing, the technical graduate would have taken one or more advanced subjects such as heat engines, wireless, or design of alternating-current machinery, etc., but such early specialization need not be taken too seriously by his first prospective employer, and the graduate should hold himself ready to re-specialize for the opening which may actually prove to be within his reach after he has migrated into industry. To support and facilitate this scheme, the really advanced work done at the colleges would then be largely of a post-graduate character, and various colleges would develop their own specialities according to the principal needs of the district and the special capabilities of their staffs and equipments. This is a very sketchy outline of a policy in engineering education which seems to me to follow naturally from the beginnings advocated by the author, and I should feel greatly obliged if he would criticize it.

**Mr. F. M. Denton:** The author has presented this paper at an opportune moment, and by no means too soon. That he is right in the main contention can, I think, hardly be disputed. Sufficient attention is not being given in our technical schools to the commercial and administrative side of engineering. It is not far from the truth to say of many of our most highly placed engineers that their actual technical knowledge represents only a small fraction of the qualifications which determine their worth as engineers. One way of expressing this is by saying, as, in effect, the author does say, that such an engineer's success depends upon knowledge of which only a small fraction was imparted at the technical school. I feel that there is much truth in this and that we must hasten to put technical training upon a broader basis. The elements of commercial and of administrative work must, if possible, be introduced into the standard curricula of our technical schools. So crowded are the engineering syllabuses already with essential matter that it would be difficult to find room even for the total of 36 hours' instruction outlined by the author, but is it the intention really to limit the instruction to this period for the whole of a course of 3 or 4 years? It might be possible in such a brief period for the lecturer to touch upon all the items of the syllabus proposed in Appendix IV, but, in my opinion, this period would be inadequate for such a course of lectures, exercises, and tests as alone could ensure the retention by the student of a reasonable fraction of the matter given. And the brief schedule of hours seems hardly consistent with the emphasis laid in the paper upon the high relative importance of the

subjects proposed. Perhaps the intention is to give 36 hours out of each year to these subjects, that is to say a total of 100 to 150 hours in the course. This on the other hand would, I think, be excessive. In the outline by Professor Gray of Cornell, published recently in the *Electrician*, the total period allotted in American technical schools to administrative and commercial subjects is about 128 hours. And now, having expressed appreciation and approval of the general trend of the proposals, I think it necessary to offer some suggestions and even criticisms. The well-known fact that, in spite of the neglect of college training in such work, British engineers have been and are to-day second to none in the world in matters of commerce and of administration, ought to be carefully considered and its meaning properly gauged before any very radical changes are made. What will emerge is, I think, this, that although our syllabuses at schools and at technical colleges make no mention of commerce or administration, the training does actually include the inculcation or cultivation of those qualities which make for success in these branches. Is it not possible that the author is emphasizing the comparatively unimportant function of a school—the imparting of knowledge—and overlooking the main function, which is the teaching of method, both of thought and of action? Time is so precious to a student, that in endeavouring to inculcate method—straight thinking and straight doing—the teacher, since perforce he must use some "subject" as his working material, ought to choose subjects which, while being essential in the training of an engineer, are those in which it is difficult, if not impossible, to be trained except at a technical school. The activities of everyday life provide no training whatever in the specialized technical branches of engineering, and if the principles of such work are not learned at the technical school they can hardly be learned at all. The principles underlying commerce and administration are, on the other hand, such as guide the ordinary activities of men. How many of our leading commercial men or administrators have ever had, or very strongly felt the need for school instruction in the principles of their work? My contention, therefore, is that the technical school's objects are first to teach scientific method in thought and in action; then to impart specialized technical knowledge based on scientific facts and principles, and only after this to deal with what might perhaps be called the "humanities of engineering." The author speaks of the six branches of this work as demanding each a special gift or faculty. This, I think, introduces unnecessary complication. What other qualifications does the engineer need in commerce and administration than those of a good personality, an instinctive knowledge of men, and a Pelmanized memory for routine, law, rules of commerce and a host of other things possessing only the remotest connection with straight thinking or straight doing? Necessary as I believe it is that we should at once act upon the broad spirit of the author's proposals, it is even more necessary still that teachers in technical schools should remember that the importance of the actual subjects taught, and of the actual knowledge imparted, is secondary to the importance of the education in straight thinking and straight doing which all technical training should afford. In this advice I know I have the concurrence of many teachers, and in mentioning the matter I would not be thought to endorse the author's statement that teachers are an exceedingly conservative class of men. Considerable experience has led me to a very different conclusion, namely, that teachers are a sane and thoughtful class of men and eminently liberal-minded. And I feel sure that the author will admit that amongst men of real technical and scientific knowledge there is but a small percentage who are entirely unconnected with the teaching profession. I say emphatically that our shortcomings in technical education cannot be blamed upon the teachers. But much blame does attach, in my opinion, to the educational authorities. The organization and administration of schemes of education ought to be largely in the hands of the men who teach—the men who are teaching, not men who did once teach and apart from having forgotten about it have no means of bringing themselves up to date. For many years past the educational authorities have formed a stumbling block in the way of education. The recent reforms—some actually made and others promised—are encouraging and we are thankful for them, but it remains true that educational reform must begin with the educational authorities. The first step in the way of introducing commercial and administrative subjects into our schools should be to bring the schools themselves into line with the fact that technical education is a great commercial undertaking, and that our technical schools form the most important commercial engineering concern in the Empire. The organization of the schools should follow sound commercial and administrative principles. The details of the reforms I have in mind are many and complex, but I should like to name a few of the chief points:—(1) The work of the various technical schools throughout the country should be co-ordinated, and better location and distribution of schools should be arranged. (2) It should be better realized that the real success of technical education as a great commercial scheme depends upon the teacher. The status of the teacher should be a high one and he should be highly paid. The location and building of our schools as well as their organization should be determined with a view to the welfare, happiness, and efficiency of the teacher. (3) The administration of the technical schools should be systematized and brought up to date. The office of a technical school should contain a telephone exchange, and every responsible teacher should not merely be able readily to keep in touch with outside commercial activities but should be encouraged to do so. (4) The antiquated and inefficient system by which the heating, lighting, sanitation, decoration, repair and general upkeep of the school buildings are made the care of the heads of the engineering departments ought to be abolished. One of our foremost polytechnics is to-day advertising for a head of its mechanical engineering department and is making it a condition that the head shall be responsible for such things as I have just named. (5) The procedure by which engineering laboratory equipment is obtained

in the London polytechnics should be revised. (6) In order to help teachers and students to keep up to date in their work and to facilitate research two things are necessary. First, the Board of Education should publish, unabridged, all the more important technical and scientific papers—both British and foreign—in the form of pamphlets obtainable at small cost. Such pamphlets, in conjunction with *Science Abstracts*, would provide every teacher and student, at small cost, with what would be equivalent to some of the most valuable facilities of an up-to-date technical library. Second, the system of the "sabbatical year" should be inaugurated, by which either one year in every five or, say, six months in every three years, should be granted to the technical teacher as a period in which, with full pay plus travelling expenses, he might visit engineering plants or factories in order to bring his own knowledge up to date practically as well as theoretically.

**Mr. A. S. E. Ackermann**: The author referred to the tendency on the part of many engineering students to despise commercial study. Thirty years ago I had a contemptuous feeling for anything connected with the commercial side of engineering, but am glad that feeling wore off, after starting on my own account, when I often found that the commercial side paid better than the purely technical. To bring home to engineering students the importance of the commercial side of engineering, their attention should be called to the salaries that engineers and commercial men respectively are paid. In a works of fair size the general manager frequently receives £2,500 a year, while the works manager, or the chief engineer, gets only £1,250 a year. That is a good illustration to a student of the relative market prices of the commercial side and the purely technical side. With regard to the suggested co-operative courses, where the students would attend one week at college and one week at an engineering works, at first sight it might appear to double the capacity of the college, for there would be one set of students studying during one week and another set during the next week; but presumably the college course would be spread over twice the time, so that the capacity of the college would not be increased. In America university courses usually last four years. Where the sandwich system is not possible, I favour the works course preceding the college course, which was adopted in my own case; but it is not always advisable for a young lad to be put into the atmosphere of workmen, though my experience of them has been a pleasant one.

**Lieut.-Colonel W. A. Vignoles**: I speak on behalf of the young officers and non-commissioned officers who have served in the Army during the war and who, I hope, will receive every consideration from employers of labour in the future. I came here to-night hoping to hear the question discussed as to what steps could be taken to help these young men. There is no doubt that some of them have lost, as far as the technical side of their education goes, a number of years of their life, but I wish strongly to impress upon members that Mr. Highfield's remarks are very true—that, although these young men have lost so many years of education, they have gained in other ways. They will look at all the problems, which they may have to face in the future, in a broader way than they could possibly have done in the past. They have seen life, and death, and many other things; and, what I consider to be of the very greatest value, they have learned to handle men, to understand men, to know what men can do and what men cannot do; from the ranks of these young men I believe we shall find the works managers and the men of the future who will control big undertakings. If they can now only acquire sufficient technical knowledge—and, according to the author, the technical knowledge required by a general manager is a very small percentage of his total knowledge—I think we shall find that they will do extraordinarily well. The other point I should like to mention is that these men have already had a considerable education in how to learn; I consider that education should be largely devoted to this. It is much more important to learn principles than facts, and I am very glad that has been emphasized to-night. The young officer goes to a cadet school and is taught the principles of soldiering; then he goes to a battalion and learns how to handle men; then, if he is wanted as a specialist, he goes back for a further course and learns to be a specialized officer in some particular branch. If we could adopt that principle in engineering work I think it would be a very satisfactory one—that every engineer should be first of all trained in principles, and how to learn and how to teach himself in after life, then he should go to the works and learn how to handle men; and finally, if he wanted to be a specialist, he should go back to college and take a course in the special subject. I think that suggestion might be considered. What I primarily wish, however, is to impress upon the meeting that many of these young men, who have fought abroad and have done such gallant service, have a great deal about them which other men, who have not had that experience, are without. In other words their experience has formed their characters.

**Mr. P. M. Baker**: I think everyone will be fairly in agreement with the principles set forth in the paper. Its general principles are undoubtedly sound, but I cannot help feeling that a lot of sympathy for the "under-dog" which has been referred to by other speakers is required: I think that our education does not in general reach the man at the bottom, and that there are not sufficient ladders to enable the man in the lower walks of the engineering industry to rise into real engineering. I feel that the training of our mechanics is vastly more important than many of us think it to be, and that it is very badly attended to at the present time. With regard to the question of the education of engineers, I feel that, if anything, we overdo and in many directions considerably overdo the technical side of their training. It is very painful, particularly when one goes abroad, to see how engineers flounder in the business side of their work. Their technical side is often particularly good, but they make the most egregious blunders in the "business" direction. The man who makes the best headway, speaking from the experience of a good many men in India and elsewhere, is the business man. I can recall to mind a great number of men in big engineering concerns in

India who have been very successful, and who in general have had very little technical education, but their business education has been thoroughly sound. I suppose the biggest electrical engineering concern in India is under the management of a man whose business ability, business acumen, and business tact are his outstanding features; they certainly carry more weight than his technical ability, although that is good. I just mention this to point out how very important I consider it to be that the business side of engineering should not be neglected. I should feel disposed to cut down the technical side very considerably rather than omit business training. One does not feel it quite so much until one goes abroad. It does not then matter whether one can do triple integrals, but it does matter that one should have the common sense and business ability to know whether an assistant's design which has involved elaborate mathematical calculations is not, say, 10 times too big owing to some numerical error. A particularly important point referred to by Mr. Fleming is that if this particular side of engineering can be dealt with by post-graduate courses in the case of the pukka engineer, we should at the same time be able to give an opportunity to the mechanic who is improving himself. There is one point which I have been up against on many occasions during the war. I have been connected with a department which has had to supply labour to factories of all sorts, aero-engine factories and the like, and as a result I have had to see many factories. The thing which caused most of our difficulties—a thing which impresses a man who knows anything about what the inside of a works should be—is that the weak spot throughout these factories has been the works management and the business side in general. It is painful sometimes to see how little ability the management has shown. I think one could hardly have found a direction in which our education is more lacking than in that of getting what is, after all, only common sense into our engineers.

**Professor F. G. Baily** (*communicated*): In the drafting of any combined curriculum, it is a common experience that all concerned, professors and external advisers alike, put in claims for the component subjects that would swell the course to impracticable lengths, were it not severely edited. Likewise when a new branch of study is mooted, some other of less importance must be pushed out to make room. Hence the author's proposals raise the fundamental question: What is the real and ultimate purpose of a college education, and should it differ in principle from other generally approved courses if it bear the prefix "technical"? I gather that the author proposes the additional subjects as an integral part of the regular undergraduate course. He mentions also something about post-graduate study, but if that is continuous with the degree course it is still a part of the educational course, while if he means the student to return after a lapse of time, it comes under another category with different arrangements and different aims. The most obvious objection to the inclusion of these subjects in a student's course appears to me to be that his experience of life is limited to his school and university, and hence he is quite unable to appreciate or take an interest in the greater part of the subject-matter in Appendix IV, while long before he has any chance of using the information he will have forgotten most of it. In after years he will come into contact with these matters, and at that time, it will be generally agreed, a fuller study of the principles of manufacture and commerce than has heretofore obtained is much to be desired. The inclusion in the college course is another matter, and I submit a broad principle on which to examine the claims for this or that extra subject. Speaking as a professor of a technical subject, I may say that we do not teach specific subjects as such. We aim at giving the student such a mental training and equipment in fundamental knowledge as will enable him to go on learning afterwards with understanding and power. So far as a few words will express, that is the guiding principle of all education, whether technical or not. How to attain that end is a long story, but it is considerably shortened if all other considerations are regarded as of secondary importance. We begin at school by teaching a boy Latin, not because Latin is useful to an engineer, but because it is one of the best intellectual exercises. So to a large extent with mathematics, so also with science. Both are incidentally useful, but we include them primarily in order to inculcate a clear and precise habit of thought, and a grasp of principle apart from the individual and concrete. Other subjects might equally serve, but these two have the further advantage of intrinsic utility. In like manner the technical subjects are made subservient to the general aim, which in the final year is directed chiefly to the obtaining of a broad and sound intellectual grasp by the thorough study of a suitable part of the subject. The details of contemporary practice are introduced only as illustrations and problems, not as the primary objects of the instruction. Of course a skilful teacher will manage to impart quite a large amount of technical knowledge in this way, and the more usefully because of the intimate association of general principles and concrete examples. They are not isolated facts; they become representative facts, and are in consequence worth remembering. The author of the paper proposes to substitute book-keeping, cost-pricing, and so forth for the study of machine design, and it is evident that he has not understood why this subject is included and made important. Machine design from fundamental principles is an intellectual exercise of no mean order. It is sufficiently restricted in scope to permit of the student gaining a fairly complete grasp of the main lines, and it brings into strenuous use a variety of mental powers. Likewise as its secondary claim it gives the student a very sound knowledge of the machinery he will probably use in after life, though he may not require to design it. Book-keeping and similar subjects are undeniably useful, but the mere fact of a piece of information being likely to be useful at some future time is not a reason for including it in an academic course of education. It must subserve the general purpose or it has no claim for a place. Plenty of advice, especially from practical men, is given us on the subjects we ought to teach and the way we ought to teach them. Employers usually ask why we do not impart more exact knowledge

of shop practice, a thing which the author condemns us for doing at all. But employers want the lad to be as immediately useful to them as possible, while our idea is so to equip him that he will learn as much as possible from the employer as soon as he goes into the works. What he can learn better in practical life we do not spend time in teaching at college. We aim at teaching him how to learn and to understand; if we do this we have justified ourselves and the years we have appropriated, and I claim that the lad is far better equipped for life than he would be if he had frittered away those years in discursive and superficial courses on all possible matters that after life might bring to him. Such a procedure produces inevitably that type of student most resented by employers, a lad who thinks he knows everything just because he really knows nothing. Give him some good tough work and a genuine insight into a few things, and he is much more humble-minded, with less reason for it. I recognize that it is only as a subsidiary course that this commercial subject is proposed, and it may be argued that subsidiary courses which are too short for a proper treatment are already in the syllabus. That is so. These courses are unavoidably restricted in scope, and much has to be delivered *'ex cathedrâ* for lack of time for fuller exposition. But it behoves the compiler to reduce the number of these subsidiary courses strictly to those required for the proper understanding of the main subjects. No doubt the author and many others will demur that a short course need not be superficial. The main principles of life can be expressed in simple form, and it is the underlying principles they want imparted, not the specific details. That, however, is the difficulty. To impart a principle to someone with no knowledge of the subject is futile. It conveys little meaning to him, and may appear the merest platitude. It is the working out of the principle that forms the gist of the teaching—the limitations, the exceptions, the cross-references to other principles, the knowing which principle is involved and how it comes in—all these matters constitute the understanding of the principle, without which it is merely parrot knowledge, only a catch word, certainly ineffective and possibly dangerous. The author mentions foreign methods of education with general approval. These differ very widely. I think he will find that the German method tended to extreme specialization, which was continued after the college course, and the education aimed at making a highly efficient machine tool for a single process. From the commercial point of view it may be satisfactory, but from any humanistic aspect it is disastrous, and recent events rather point a moral. On the other hand the American educational scheme resembles that wide-embracing curriculum which I contemn, and of the results on the American student I have never heard a good word from anyone. Knowledge have they, but not understanding. For fear of disturbing the *entente* I will not enlarge on this topic, but I do not consider it to be a happy example for our author's theme. In any scheme of education, however clearly the primary intention is laid down, there is always room for discussion about the best procedure, and for differences of opinion about the proportion of other matter to be introduced that is of practical use. Even with a child, spelling and the multiplication table bulk largely, not for their value as mental training, which is small, but owing to the extreme utility of that knowledge. In a technical education the name indicates that while it must be a genuine education, it is an *ad hoc* training. The definitely useful information is devoted to a specific end, and the proportion may occupy a larger part than would be approved in the perfect scheme devised for "a scholar and a gentleman," who had not subsequently to earn his own living. It is a matter of proportion, but it is fatally easy to squeeze out the less obvious exercise of the mind, and to choke the syllabus with things of utility. They are easy to teach, they are easy to learn, and they give a great appearance of progress on the part of the student and an up-to-date air about the whole thing. Inexperienced teachers usually begin that way, the more so if they are well-informed practical men. Their minds are full of detail that they find useful in their business, and the guiding principles have become so much a matter of course that they hardly formulate them, and do not think of bringing them out sharply and clearly. Such courses are excellent for post-graduate students, who are already in practical work. They are ready to appreciate the facts, to compare them with their own experience, and in some measure to sift and analyse them. Lest I be misunderstood, let me say that I by no means hold that a study of the principles of business lacks educational power. The author's syllabus contains much that admits of, and indeed requires, profound study. It is a curriculum in itself, and fails as a subsidiary subject in that it is too foreign to the rest of the course, and too much outside of the student's experience to allow of a short treatment. Let it be withheld for three or four years and delivered to an already experienced audience, and the number of lectures proposed will be quite reasonable. I, for my part, shall endeavour, as soon as education has settled down again, to arrange in my city lectures on this subject and along these lines at such times as will permit the right kind of audience to attend.

**Mr. Charles Bright, F.R.S.E.** (*communicated*): As a small supplement to this important paper, perhaps I can usefully call attention to the fact that amongst other counteracting advantages the war has certainly aroused parents to the desirability of a changed educational curriculum at our public schools, as well as at Oxford and Cambridge. Soon after hostilities set in there occurred, it will be remembered, a general discussion in the Press on the subject, with the result that a Committee was formed which had for its special object a reformed public-school education. I became a member of this Committee, of which Lord Desborough was Chairman. The first step taken was to apply to all the parents of the leading public schools (27 in all) inquiring whether they would favour a fuller education in science and modern languages, even though involving a smaller amount of time being spent on Greek and Latin. As the largest and perhaps the most conservative school, Eton may be usefully quoted as an example. Out of some 900 parents to whom the circular was sent, 536 replies were received, of which 512 favoured such a change,

12 were against, and 12 neutral. In other instances the result was still more striking. The next step taken was to form a deputation to attend at the Head Masters' Association of that year. The deputation was exceedingly well received, and seems already to have had some effect at several of the public schools. Whilst a firm believer in the public school as the best means of forming the right sort of character—for which the Allied Forces have much to be thankful—I cannot help thinking that most of what the author pleads for will be more readily brought about with the changed school curriculum to which I refer. I should like further to endorse some of Mr. Highfield's remarks in the discussion relative to the great improvement effected in many of the younger generation by their experiences at the Front. Many have undoubtedly become for the first time competent to manage men effectively, and this is really one of the most important characteristics very often of a successful engineer. Having sometimes to select candidates for important positions in Australia, I am usually struck with the small proportion who are embued with any such capacities, as compared with those eminently efficient technically.

**Mr. W. C. Clinton** (*communicated*): The author has succeeded in making out a case for some alterations being now advisable in the normal university curriculum for engineering students in these islands. The suggestions put forward are, however, so far-reaching that their adoption even in any considerable part would necessitate the extension of the ordinary three-year course by a year at least—a change for which the time is not ripe, at any rate in this country. If engineering students were to begin their college courses with a fair knowledge of the methods of book-keeping, a subject which could with profit occupy some of the time hitherto devoted to the study of dead languages, there would be more chance of benefit being derived from a course or courses of lectures on such subjects as shop costs, accountancy, the law of contracts and the like, during their final year at college. One cannot help feeling, on reading the paper, that too much stress is laid on the acquisition of knowledge as such, and on making the embryo engineer immediately useful to his prospective employer. Extended experience in engineering teaching will convince one that the various subjects of the syllabus are to be used primarily as means for the cultivation of a logical habit of mind, of a faculty for reasoning correctly from given data, and only secondarily for the acquisition of knowledge or for being of immediate pecuniary value to someone else, although both of these considerations are of importance. Knowledge not in continual use is forgotten in after years, but the habit of mind engendered in its acquirement remains. In so far as one or more of the subjects indicated by the author could be treated so as to aid in developing the mind, the knowledge acquired being regarded as a useful by-product, they become on a parity with the technical subjects of an engineering course, and their ultimate inclusion in it will then become possible after alterations and abbreviations of existing courses of the kind which have been admitted as necessary in the past in order to deal with new technical developments.

**Mr. J. F. Driver** (*communicated*): I am quite in agreement with all the suggestions that the author puts forward, and my only adverse criticism would be that he does not proceed sufficiently far in his suggestions for reform. There is, in my opinion, not the slightest doubt that our present system of training is altogether too much concerned with the production of the designer rather than the controller of an engineering business or office. Practically all the stress is given to the mathematical and physical sides of the subject, in spite of the fact, which is so clearly brought out by the author, that a considerable part of this class of knowledge is not as a rule used by the engineer in dealing with the problems that come before him in his daily life. The designing in these days is certainly confined to the few specialists, and we have gone beyond those days when it was assumed that a thorough engineer had a working acquaintance with all the knowledge required by all his assistants. If the same kind of basic attention were paid to the administrative and commercial sides of an engineer's training, leaving the few who are peculiarly fitted to specialize on the ultimately higher technical branches, I have no hesitation in saying that the industry as a whole would benefit. My chief reason for contributing to the discussion is based upon the author's remarks under the heading of practical training "Co-operative Courses." He states that "Unquestionably the ideal method of teaching engineering would be always to give the instruction in the practice and the theory simultaneously." With this I fully agree, but why not go further and state that the ideal method would be to give such concurrent instruction under the same organization controlled by those who are primarily concerned in education rather than the making of dividends? In other words, why not give the necessary works training side by side with the theoretical instruction in the technical college, which would mean that the engineering workshop would be ultimately controlled by the technical college authorities? That this is a practicable proposition is abundantly shown by what has been done at Loughborough. Attached to the Technical College in this town we have an instructional factory capable of accommodating 500 workers at the same time. The works are exceedingly comprehensive in character, in so far as they stretch over practically the entire range of mechanical engineering, from the foundry through to the inspection department, with full equipment and provision for testing and for estimating, costing, and purchasing. This organization has been developed for the purpose of training workers for the production of munitions of war, and it is hoped that with the co-operation of the Board of Education and representatives of the engineering industry, it may be retained as an Engineering Training School along the lines broadly suggested in this paper. The students would spend at least half their time in the works, and the remainder of their time in the lecture rooms and laboratories of the College. Their theoretical training would include accountancy, works organization and methods, costing and estimating, and during their period of study they would have an opportunity of going through all the departments and offices of the factory. From the commencement of the scheme, the

factory has been maintained upon a productive basis, with the entire elimination of the "exercise." Thus, at all the periods in his practical training, the student is brought face to face with the necessity for output, and the obligation to live up to a promise of delivery; yet at the same time his tuition is in the hands of men sympathetic towards education. Such men require very careful selection, for it is of paramount importance that they shall be men who have had wide engineering experience, and yet fully sympathetic with the necessity for giving due attention to the instructional part of their work. Such an organization also tends to alter the general staffing arrangements of the academic institution. Its members must be comparable as regards both salary and experience with persons holding similar positions in commercial life, whilst the well-known fetish of the teacher's holiday must be abandoned, since it is apparent that if the factory is to run under works conditions, engaged upon actual contracts, it cannot be closed down for any period beyond the normal holiday period in similar works establishments. What I am anxious to bring before the notice of members is that the above institution at Loughborough has such a scheme which has now reached the stage of being a practicable proposition. It is a scheme which is now working, and which we have every hope will yield excellent results. One realizes from the commencement that its students will not expect to reach the scientific level usually taken by university graduates, but on the other hand they will possess a practical working knowledge of engineering, and a broad general education covering its main principles, not only on the strictly technical side, but also on the humanistic and business side.

**Professor C. L. Fortescue** (*communicated*): It would appear that the author has raised again, in a fresh light, the old problem that was discussed at such length before the Institution of Civil Engineers some eight years ago, viz. the nature of the compromise between "Work to be done" and "Time available." It is probable that the most critical period of an engineer's life is his first responsible appointment, at an average age of about 28 years. This may be regarded as the end of his novitiate and the beginning of his most productive period. From this point onwards he will be confronted with problems and difficulties of every kind—technical, administrative, moral, and psychological. Of these problems and difficulties, it is unlikely that answers to more than 40 per cent can be given to him beforehand during his novitiate, or can be found by him in books of reference. For the solution of the remaining 60 per cent—often the most fundamental problems of all, such as the control and leading of men—he must rely on his own character and trained intellect. The problem of his education thus reduces to a question of how much time should be spent in providing him with the ready-made answers to the minority of problems, viz. those that can be foreseen, and how much time should be devoted to the training of his intellect to enable him to cope with the majority of problems, mostly those that cannot be dealt with beforehand. The tendency in some quarters has certainly been to concentrate on the provision of ready-made answers. This is natural because the demand of the employers of the young engineers has always been for men who will become more or less productive in the shortest possible time. Moreover, the results of this method are more tangible and can be more easily assessed by examination. The influence of the training on the intellect is not a thing that can be easily measured by examination, and often the results may not be evident for some years. Ultimately, however, the training of the intellect becomes effective—not uncommonly at a time when the answers to the specific questions are being forgotten—and during the productive period of an engineer's life it is his intellect and character that determine his effectiveness. Any suggestions for the introduction of such subjects as workshop organization, costing, book-keeping, administrative methods, etc., should be considered from the point of view of their value in training the intellect of the student rather than from the point of view of their immediate commercial value. It is an undoubted fact that our best teachers and teaching establishments do combine the training of the intellect with the provision of ready-made answers to specific problems. But there is a limit to the extent to which the two functions can be combined, and the results now being obtained are the consequence of long experience and careful observation on the part of extremely capable men. If equally good, or better, results can be obtained by the introduction of the new subjects, well and good: let us have them. But let both the employers and the teaching profession consider this innovation from the intellect-training point of view rather than from the point of view of immediate productiveness, before any definite steps are taken. Finally, could it not be ascertained in the course of this investigation what proportion of the successful works managers of to-day, i.e. the £2,000 a year men and upwards, can point directly to early instruction in administrative subjects as the cause of their success?

**Mr. F. Gill** (*communicated*): As one who has had to deal with a considerable number of young engineers from the colleges, I may perhaps express an opinion on their training. A certain group of these men have been very successful—I do not remember a single failure—but they were selected in a special manner by the professors, who were good enough to help me; others who came in the ordinary manner were more varied. But I think the author has touched a weak point in the training; an engineer requires to be other things besides a designer, and I rather imagine time might usefully be abstracted from what may be called the designing studies and given to the study of how to select and construct with the view of earning a profit. The engineer in any large concern is very much interested in this question of profit-earning; when he has designed an extensive system, he has very nearly settled whether it shall be profitable or not. The amounts required for interest and depreciation are settled, the costs of coal, water, oil, and stores are largely settled, so are maintenance costs; it is true that the operating force can affect economies or waste, but these are largely marginal, and the operators are helped or hindered by the original lay-out of the engineer.

I do not think that their responsibilities in this matter are always sufficiently impressed on the students, nor that their training is directed to this end. In planning out extensive works, the questions of how much to construct to-day, and how long to defer construction, constantly arise and can only be settled by reference to the comparative costs. The methods of doing this are well known and can easily be taught, but I do not remember a case in which a student was able to handle such a question, even when the costs were given. I believe that administration, organization, and even such matters as tact can be taught. Illustrating this, I may say that at Harvard they are teaching the subjects in the following lists, although not part of the engineering course. The lists are interesting as illustrating the idea that certain subjects (hitherto thought to be only acquired from experience) can be taught to the students—and at several of the American universities there have been started recently courses on employment management.

Some courses in the Harvard Graduate School of Business Administration :—

| | |
|---|---|
| Marketing .. .. | Marketing,<br>Advertising,<br>Purchasing. |
| Industrial Management .. .. .. | Factory management,<br>,, ,, problems,<br>Accounting principles,<br>Marketing,<br>Business statistics,<br>Taylor system of management. |
| Transportation .. | Railroad organization,<br>,, accounting,<br>,, operation,<br>,, rate-making,<br>Water transportation. |
| Lumbering .. .. | Principles of forestry,<br>General lumbering. |

**Mr. W. H. Grinsted** (*communicated*) : It appears to me that in the discussion of this paper we have had statements of the experience and opinions from only two classes, namely, the employers and the professors, from points of view which seem somewhat opposed. When the doctors disagree, the patient who has been operated upon may perhaps put in a word. I should like to state my experience with regard to the need for administrative subjects in the engineer's training from the point of view of the student. I left the Central Technical College at the age of 21, feeling that I should at least make an attempt to earn my own living on reaching that age. I had the advantage of the instruction in workshop accounts to which Professor Howe stated 12 hours were devoted during the third-year course. At that time the attitude of the students towards this subject was anything but that of devotion. I understand it is better now. I took a position in the technical department of a large operating company It was not until then that I fully realized the importance of the commercial side of an engineering and highly technical undertaking. The technical department, although it was by no means unimportant, filled but a corner of the whole organization. I give these personal details only to illustrate the suggestion I am about to make, namely, that instruction in administrative subjects should be given by the engineering colleges to post-graduate students in evening courses. Realizing strongly for the first time the importance of the commercial side, I should at that time have jumped at the opportunity of attending lectures on these subjects at my old college on, say, two evenings a week during the first two years of my employment. After the intensive application during a student's third- or fourth-year course at college has ceased, he has a real need for something on which to exercise his mind. He is, probably for the first time, in contact with commercial and administrative matters, and he would welcome the opportunity to become acquainted with the principles, and what one may call the theory, of these subjects at the same time as he is becoming acquainted with their practical side. The great difficulty which the student experiences when they are treated as part of the graduate course, is that he has no concrete ideas of the things dealt with, nor does he realize their importance. This is the reason for the tendency referred to by the author, and for the attitude of myself and other students towards the workshops account class to which I have referred. The suggestion I have made seems to me to overcome entirely the difficulty of finding sufficient time during the college course. When the author first referred to 36 hours, I expected him to add "per term," and was extremely surprised to find that he proposed a total of only 36 hours' instruction in the five important subjects in his list. I do not see how the engineer with only such a small amount of instruction is to compete for administrative positions with non-technical men who have been able to devote a very much larger proportion of their training to commercial subjects. The difficulty of the student's attitude towards these subjects would also, I think, be overcome, for very soon after he leaves college and enters the commercial world a student begins to realize the use and importance to him of these subjects. With regard to the remarks of some of the teachers, particularly Mr. Denton, questioning the importance of these subjects compared with that of purely technical subjects, I would remark that from my experience I have not the slightest hesitation in saying that they are at least equally important. I have badly felt the need for a proper and systematically acquired knowledge of commercial and administrative subjects. Such as I possess has had to be acquired by a practical and unsystematic method in which the principles have appeared long after the facts have been acquired; indeed, I am quite certain that very many of them have not yet emerged.

**Mr. H. C. Gunton** (*communicated*) : To many engineers who have already fought their way through an appreciable portion of their career the author's views as regards education and training will appear very convincing, and it seems clear that, unless some such modifications are effected, the engineer's contributions during and after reconstruction will be unnecessarily restricted and his remuneration will continue to be inadequate. But there is another side of the question which is suggested by the points brought out in this paper,

particularly with reference to the author's concluding remarks in which he points out the connection between the education and training of the engineer and his status. It appears that there are three conditions essential to the realization of the results hoped for by the proposed educational reforms. First, there must be the recognition that the engineer should be relied upon in more than the restricted technical capacity which it has been usual to regard as representing his limitations by certain classes of employers. Secondly, the recognition that the professional advice of a thoroughly qualified and responsible engineer should be considered by those having the necessary qualifications for the comprehension of that advice, is another condition and one which is, no doubt, more difficult to obtain. The third condition is to foster the engineer's confidence in, and respect for, his own status, and to afford him every possible aid in maintaining that status in the difficult circumstances which occasionally arise, not only as between himself and his employer, but with members of his own profession. The constitution of a General Engineering Council, as proposed by the author, would appear to be the only way to ensure that the first two conditions are brought, and kept, before the notice of those whom the author describes as "the leaders of the nation," and to ensure the proper qualifications of engineers. If amongst the functions of that Council were the maintenance of a Standing Committee to whom engineers could turn for advice and guidance in difficult cases of procedure, it would be of great assistance to the profession. There are many matters which of course could not properly be referred to such an authority, but the mere existence of potential professional support would in itself afford a stronger measure of protection than appears to exist at present. It is suggested, as a preliminary measure, that a fully representative Committee should be elected under the auspices of the Institution to examine and pursue the various aspects of these subjects in all their bearings.

**Mr. A. J. Stubbs** (*communicated*): I was somewhat disappointed that the very lengthy and interesting discussion failed to bring out what I feel sure was prominently in the author's mind when he prepared his paper—a paper of commanding importance. As I understand the author it was absolutely foreign to his case to discount in the least the importance of the technical side of the engineer's function. I think his argument would briefly run thus:—The engineer, to be a well-trained engineer, must be 100 per cent efficient as an engineer throughout his career whatever sphere he fills. As, however, every engineering job calls for other faculties in a greater or less degree, the engineer to be 100 per cent efficient in a given post must have been trained in and have developed other than technical faculties, and must recognize that the limit of his success will be largely controlled by such acquisition. In the course of his career, for example, the book-keeping faculty may represent as much as 30 per cent of his value if he be a development superintendent, but will represent only 15 per cent of his value as traffic manager, while if he should attain the position of chief engineer or general manager that faculty will only represent 5 per cent of his value. Similarly, the technical faculty in the various positions respectively would represent 5, 10, 40, and 25 per cent of his value; not necessarily, be it observed, of his faculties. And the corollary is that it is essential to the due and proper execution of each of the functions enumerated that the position be occupied by a trained engineer—100 per cent efficient in respect of the proportion of his duty that is technical—that it should be recognized to be as anomalous for the general manager of a great engineering concern not to be capable of performing authoritatively his 25 per cent technical function as that his 50 per cent administrative faculty value should be wanting. A single consideration alone will demonstrate the necessary correctness of this reading of the diagram of Appendix III—it cannot be that the 85 per cent of the foreman in technical faculty is to the same "scale" as the 40 per cent of the chief engineer. There are many very interesting deductions to be drawn from these diagrams. Perhaps I may be permitted to give one—a far-from-brilliant engineer may be selected as development superintendent, but if a 100 per cent efficient engineer be put in the position, during the time that only 5 per cent of his value is engineering he must carefully guard against that faculty becoming atrophied or he will have no reason to complain if he finds that his engineering outlook is blocked. Of course these diagrams demonstrate the inconsistency of concerns which, properly refusing to recognize the eligibility of engineering clerks as such for promotion to engineer rank, yet so organize that their engineering operations shall ultimately be adjudicated upon by non-technical administrative staff.

**Professor Miles Walker** (*communicated*): I am in general agreement with what the author says as to the advisability of giving instruction in administration, organization, commercial law and specification. At the Manchester College of Technology we have for some years dealt with these matters in lectures on economics and works management; and lately a Director of Industrial Administration has been appointed, under whom the study of these and kindred subjects will be further extended. It must be remembered, however, that while these things are important, the technical part of the instruction is still more important, and the students' time-tables are already very much crowded. If we compare the times given to the study of various subjects in the curricula of American and German engineering colleges, we shall find that the total numbers of hours in the course—which in those countries generally extends over four years—are very much greater than the numbers of hours given to corresponding subjects in the three-year course of a British university. I give in Tables 1 and 2 two typical instances, one of an English university and one of a German university respectively. In order to find adequate time for the study of all these subjects, two alternatives present themselves: we must either extend the university technical training from three years to four years, or we must arrange matters so that the student carries his knowledge of mathematics, physics, and chemistry up to the Intermediate standard before he enters the university. This can be done under the provisions that the Board of Education is making

for the higher study of science in secondary schools. The objection to a four-year university course is that most parents view it as of too long duration, having regard to the fact that it has to be followed by a two-year works apprenticeship. In Appendixes II and III the author gives estimates of the qualifications needed in certain grades of officials. One must of course assume that he is dealing only with qualifications that can be imparted by training; he is necessarily leaving out of account natural qualifications, which he will admit are of equal importance. Now there is a qualification for the engineer which comes, perhaps, more by training than by nature, and the connotation of which cannot be expressed by one word. Perhaps

TABLE 1.

*Electrical Engineering Course at an English University.*

| Subject | Number of Hours in Three-year Course |
|---|---|
| Electrical laboratories | 570 |
| Mathematics | 500 |
| Mechanical engineering lectures | 400 |
| Electrical engineering lectures | 280 |
| Engineering drawing | 320 |
| Mechanical laboratories | 270 |
| Applied physics | 240 |
| German (or French) | 240 |
| Electrical tutorial | 200 |
| Engineering workshop | 200 |
| Electrical design | 180 |
| Chemistry | 200 |
| | 3,600 |

TABLE 2.

*Electrical Engineering Course at a German Technische Hochschule* (1913).

| Subject | Number of Hours in Four-year Course |
|---|---|
| Electrical laboratories | 842 |
| Higher mathematics | 790 |
| Mechanical engineering lectures | 1,140 |
| Mechanical laboratories | 842 |
| Engineering drawing | 634 |
| Electrical lectures | 584 |
| Electrical design | 248 |
| Experimental physics | 248 |
| Chemistry | 72 |
| Political economy | 186 |
| Banking and stockbroking | 62 |
| Commercial engineering | 31 |
| Finance | 26 |
| | 5,705 |

the word "integrity" most effectively expresses what I mean. Whatever be its name, it is the quality that, in my opinion, more than any other makes the difference between a successful engineer and an unsuccessful engineer. The student who has acquired the habit of grasping each new idea presented to him and making it completely his own, and of overcoming difficulties as they arise, makes very much more rapid progress in his work than the student who is content with a vague general view of the matters brought under his notice, and who evades the difficulties that present themselves. The right habit of mind is, I believe, largely a matter of training; and a great deal more attention should be given to the acquiring of it by those who have the teaching of the pupils at school. Very great improvements are required in the teaching of children to think efficiently; and in many of our schools not the slightest attempt is made at encouraging logical and efficient thought. Indeed, far from logical thought being encouraged among scholars, many of them are compelled to spend years of their school life in the study of such illogical subjects as English spelling: so much so, that 90 per cent of them lose their faith in their power to arrive at correct conclusions by deductive reasoning. The university is then asked to take these wrecks from the rocks of British spelling and convert them into logically-minded engineers. We do our best; but many are broken beyond repair. By integrity I mean more than this direct habit of mind: there is that conscientious scruple which compels a man to get at the truth, however difficult it may be to define, and to state the truth, however unpleasant it may be to state. There are the tenacity, perseverance, self-sacrifice, and faculty of taking infinite pains, which enable a student to get at a secret of Nature when others would have given up. All these qualities we may include in the concept "integrity." The university course must also be ordered so as to augment this quality in the students' character. I believe that we shall come to realize that far more depends upon the manner of training in this respect than upon the subjects actually taught at the university. There are other matters to which enough attention is not given at our engineering colleges at the present day, particularly at those situated in engineering centres. These are the atmosphere of university life and the physical well-being of the students. They are matters the discussion of which would occupy more space than is here available. They would be best dealt with by reforming our universities so as to take our young engineers, and students generally, away from town life altogether and give them more beautiful and healthful surroundings during their student days. Unfortunately, we do not have in the British Empire a great, modern, efficient university, in the sense in which these adjectives can be applied to some of the best American universities. One can imagine the campus of a really great university somewhere up on the Pennine Range: well-designed modern buildings, interspersed with trees and gardens, far away from the vicious town, and within reach of mountain summits. A really great university will create for its students an atmosphere of beauty and restful inspiration that is impossible in our town-drowned colleges. We wish to give to our young men and young women a memory of their student days that is lit with bright skies and scented with heather, not clouded by the gloom of city students' lodgings. The scientific equipment of such a university of the British Empire should be second to none in the world. America has found that the money spent on the highest university education brings benefits whose money value alone far exceeds the expenditure. There is a movement in most of our towns to subscribe money for some

memorial to commemorate the work of their citizens in the war. It would be a good plan if part of the money so raised could be devoted to the founding of a really great university for the British Empire such as I have outlined.

**Lieut.-Colonel W. A. J. O'Meara** (*in reply*): The author desires to express his thanks to his audience for the very patient hearing given him and particularly to those who have taken part in the discussion viva voce and in writing. He feels that the qualifications to the statements made by him in his paper have not, in all cases, received due weight, whilst in some instances he has perhaps been misunderstood. For example, he has nowhere expressed the opinion that complete instruction either can or should be given during the normal engineering course in commercial and administrative subjects, indeed, his views, as stated in the paper, are directly to the contrary (see page 232); he has not proposed that only 36 hours' preliminary instruction should be given in the branches of study mentioned by him—on the contrary, he has recommended that at least that number of hours should be devoted to instruction in the elements of those subjects during the normal engineering course (see page 232); he has not proposed the adoption, in British colleges, of the identical practice of other countries—on the contrary, he has pointed out that the specialized education (the expression "specialized education" being used in a broad sense to distinguish the education of an engineer from that of an accountant, that of a medical practitioner from that of a barrister, etc.) and training of an engineering student should be based on the nature and extent of the several faculties that are needed by employés or officials in engineering undertakings (see page 229). These are but a few of the points in relation to which misconceptions as to the views of the author seem to have arisen. As a matter of fact the author's main contention is that the engineer requires, in his everyday practice, knowledge in a wider range of subjects than that provided by the instruction given at the present time in the normal engineering courses of British universities and colleges. The discussion on the paper has resulted in a great volume of evidence on the subject being produced by those who have taken part therein; on the whole, this evidence, the author thinks, goes to prove the necessity for providing instruction to engineering students of the kind suggested. Further, it seems also to be generally admitted that the period of three years comprised in the normal engineering course is really inadequate for the purpose of providing engineering students with instruction in many indispensable subjects, and it is tacitly recognized that resort must be had to graduate courses in order to complete the education of the engineer. In these circumstances, assuming that there is concurrence in views as regards the subjects in which instruction should be given to the future engineer, the question arises: What is the most advantageous scheme for the distribution of the subjects? Should the whole of the normal college course be devoted to instruction in technology and the whole of the instruction in administrative and commercial subjects be deferred to graduate courses, or, on the other hand, should some of the instruction in technology be postponed in order to allow at least some instruction in the elements of administrative and commercial subjects indispensable to all engineers? It is fully recognized, and so stated in the paper, that the range of administrative and commercial subjects is so wide as to preclude the possibility of any but preliminary instruction in the elements thereof being included in the present normal engineering course. In endeavouring to arrive at a solution of the problem before him, the author passed in review his own personal experiences in the various technical and administrative positions he has held during an active career of 33 years in different parts of the world. The first prominent fact which he had to recognize was that the majority of men who carry on the engineering profession are not employed as specialists, e.g. teachers, designers, research workers, etc., but are men engaged in general practice, either in an administrative position, or in a commercial capacity, or in some executive grade. And the second point which the author had to bear in mind was that many engineers, on the completion of the normal college course, find employment in remote localities, at home and abroad, where opportunities for further instruction by attendance at courses are either non-existent or only few and far between. Under these circumstances, the author felt that the present curricula, however well suited for those about to become specialists, failed to meet the needs of those students who intended to start in general practice as engineers. For this reason, he has pleaded for a slight revision of the present curricula with a view to the inclusion during the normal college course of a small amount of preliminary instruction in administrative and commercial subjects, in order that students might have brought before them the importance of the business side of their education and so that they might be put in possession of the sources of information on the subject. The author's hope is that those who are not fortunate enough to be in a position to continue their education by attendance at graduate courses may, in this way, be at least placed in a position to improve and extend their knowledge in essential matters by private study; he is confident that a knowledge of the leading principles of the subjects in which instruction is recommended by him can be imparted in the number of hours stated. The author anticipated, correctly as is now proved, that any proposal to include additional subjects in the normal college course, tending to encroach upon the time allotted to instruction in technology, would be strongly resisted, and the proposed scheme was therefore based on the bare minimum of time necessary for a preliminary course of instruction in business subjects. It seems to him somewhat unreasonable on the part of those who oppose his views to argue, on the one hand, that the proposed course is too short, and, on the other, that, short as is the course, time cannot be spared even for the small number of hours suggested. The proposal has been made that instruction in administrative and commercial subjects should be given as a part of a boy's general education; the author concurs in this view, but what will the schoolmaster have to say to this proposal? After all, instruction in

science has prior claim on any spare time that may be available in boys' schools, and this should not be overlooked. The idea seems to prevail in the minds of some, that the teaching of the leading principles in the subjects proposed in the paper will somehow do violence to the accepted aims of all education. The author has been unable to discover anything illogical in the principles in question, nor is there anything of a character subversive of mental discipline in them. On the contrary, in his opinion the principles involved in administrative and commercial subjects afford a training of a useful order in connection with the handling of men and with the conduct of business transactions, in every way equivalent in value to the mental training obtained by the study of mathematics and pure science. The author is convinced, from his own experience, that a study of the subjects in question undoubtedly inculcates clear and precise habits of thought and provides a student with fundamental knowledge which will enable him to go on learning with understanding and power.

Mr. Fleming states that he can scarcely agree with the paragraph on page 227, headed " Scope of the Engineer's Responsibilities." It is not clear to the author what is the particular statement in the paper which does not meet with approval. If Mr. Fleming fears that the widening of the basis of the engineer's education will make him narrow-minded and less useful, the grounds on which such a conclusion is based are not evident to the author, whose experience, gained in many fields of activity, has taught him that the wider a man's knowledge the more capable is he as an administrator and as an executive officer. Mr. Fleming has correctly interpreted the diagrams to which he refers. The word " faculty " is used to denote the mental power or ability to do anything ; it represents an innate quality in man and can be developed by suitable instruction and experience. And it is the development, by suitable instruction, of as many as possible of the human faculties coming into play in the engineering career that the author is urging in his paper ; he firmly believes that systematic instruction coupled with experience is a better mode of arriving at the results desired than by leaving everything to haphazard experience. M. Fayol's method of grouping the transactions of an enterprise under six essential functions, though novel, appears to the author to possess much merit from an administrative point of view, particularly when used for the purpose of analysing the nature and extent of the faculties which should be most developed in those required to fill important positions in an undertaking. This method deserves to become more familiar, and especially as it is by its means that those in responsible positions are likely to discover whether, for instance, in the case of a managing director the measure of his technical capacity shown in Appendix II, i.e. at 5 per cent of his total capacity, represents the general requirements or that of a particular case only, a matter on which the author hesitates to express a definite opinion—the figures given in Appendix II relate to particular cases and do not state a general proposition. Did manufacturers only admit young men without the payment of a premium into their workshops in order to meet the demands of their own factories exclusively, there would certainly be no merit in their action. But in cases where manufacturers are ready and willing so to admit young men, whose intention is to proceed later to the Colonies or to seek employment with firms other than those with which they have received their practical training, the action of such manufacturers stands on a different plane and the author still ventures to think that the term " patriotic " correctly applies to those who so act. The author is of opinion that fatigue study is properly placed under the " Technical Function," since it is only persons possessing the technical faculty who can efficiently devise means to obtain the information required. Once the information sought is acquired, its application, it is agreed, falls under the " Administrative Function." The author regrets that the pressure of his engagements prevented him from making Appendix I as comprehensive as he had wished to make it ; it was compiled solely with the object of giving a very general idea of the nature of the transactions falling under the several functions (see page 228). The education of juvenile and adult workmen is certainly an important matter and so is research, but they are not essential functions of every enterprise. Arrangements for the education of juveniles and adult workmen and also for industrial research form part of the " Administrative Function," whilst the actual education of workers and the carrying out of industrial research form part of the " Technical Function " : they are matters which should receive careful attention in every undertaking of importance. Research work, it seems to the author, should be entrusted to a selected few who have a special aptitude for carrying out investigations and drawing proper and useful deductions therefrom ; it can never form part of the ordinary education and training of the general body of engineering students. For these reasons it is that the author omitted to deal with the subject in his paper. The author was aware, when he wrote his paper, of the excellent arrangements made by the University of Manchester in connection with instruction in administrative and commercial subjects. Manchester was more particularly in his mind when he referred to centres, other than London, at which such instruction is afforded (see page 233).

The view is expressed by some of the contributors to the discussion that the training of an administrator is a matter entirely of experience and that his stronghold is tact. The author agrees that tact is a most important qualification in an administrator, but it is by no means the sole one ; this fact has not been overlooked in the scheme of instruction recommended (see Appendix IV, " Bases of Administration :—the art of handling men ") ; however, he joins issue with those who hold the view that instruction by word of mouth in " administration "—and included therein tact—possesses no value. The author's personal experience has shown him that whenever certain broad principles connected with administrative duties inculcated in him as a young man have been disregarded trouble has invariably followed ; whereas, whenever, under similar circumstances, these principles have been strictly observed matters have always progressed smoothly. Unquestionably, experience adds enor-

mously to the value of viva voce instruction given in "administration," but surely this is the case in all branches of learning involving the application of the knowledge gained from textbooks and lectures to the practical everyday affairs of life. The wide experience many young men have had in the army during the war will undoubtedly prove of immense benefit to them in administrative positions in civil life; they will, if observant, have learnt much of human nature, the susceptibilities and the general aspirations of men. It only wants a certain measure of wisdom on their part to apply the lessons to be derived from such experiences to the practical affairs of everyday life: the success of those who realize this fact and act accordingly is assured. The proposal of Professor Bacon that two kinds of degrees should be recognized is sound as an abstract proposition. It is presumed that Professor Bacon intends that every engineering student shall some time or other study for both the degrees; unless a student proceeds to the proposed B.A. degree obviously nothing would be gained by the change suggested. Unfortunately, few parents have the means nowadays to admit of their maintaining their sons for the longer period that would be required to enable them to take both degrees, and for this reason the proposal hardly comes within the range of practical politics. The question is asked: How many of our leading commercial men or administrators have ever had, or very strongly felt, the need for school instruction in the principles of their work? Our commercial men and administrators have certainly shown by their reticence on this subject that they possess a considerable measure of native wisdom. But it must not be assumed therefore, on the one hand, that no need for school instruction exists, and, on the other, that all, or even a great majority of, our commercial men and administrators are sufficiently qualified to meet satisfactorily all the demands made upon them. As a matter of fact, school instruction has now been available in London in administrative and commercial subjects for many years, and many men, some past the school age, have taken advantage thereof; that they unfortunately form a small minority is amply demonstrated by the facts often disclosed in arbitration proceedings and in our Courts of Law during the hearing of cases in which commercial men and administrators are concerned. In such cases the competence of our commercial men and administrators is always under trial on one side or the other; often the evidence given at such proceedings and trials is of a character to show that a great necessity exists for a radical reform in the commercial education of our business men and administrators. The author agrees with Mr. Baker that the training of our mechanics is worthy of serious consideration. It would be enormously to the benefit of the industries of the country if some suitable scheme, or schemes, could be worked out on a scholarship basis —necessarily State-aided—in order to provide our mechanics with a sound education and training. Such courses would naturally differ in character from the instruction afforded at the present time to ordinary engineering students. The claims of the young men who have won the war should most decidedly receive the most sympathetic and the very strong support of everyone; special facilities should be given such of them as possess aptitude for the engineering profession with a view to assisting them to join its ranks. The subject is one which requires separate treatment: the arrangements in connection therewith would necessarily be of a temporary nature only, and the matter seemed therefore to be outside the scope of the paper. As regards "Co-operative Courses," the author recognizes that this method of instruction cannot be adopted universally in this country, and he therefore limited his recommendation to the desirability of an attempt being made to introduce such courses "in the case of engineering schools and colleges situated in the great industrial centres." As regards the criticisms directed against the proposal, the author ventures to suggest that no progress in education, or for that matter in any other direction, is likely to be made by the adoption of an attitude which consists merely in turning down a proposal without any practical trial and in heaping ridicule upon it. Co-operative courses are well spoken of by those who have given them a fair trial, and it would seem that the most practical method of determining their value, either generally or in special cases, would be to "test out" one or more schemes of the kind in order to ascertain whether they "prove in," or not, on their own merits. No disparagement of those belonging to the great teaching profession was intended by the author by the reference made by him to the conservative tendencies, with rare exceptions, of its members. Admittedly, the professors have a just cause of complaint against employers as a class, since, whilst criticizing the product of the engineering schools, rarely has it been the case that employers have made constructive suggestions for improving the courses of instruction, so as to meet the practical needs of the situation. The author has the highest regard for the members of the teaching profession: he recognizes that without their valuable assistance this country would not be in a position to maintain its supremacy in the fields of industry; he also readily acknowledges that some part of the credit for winning such supremacy is undoubtedly due to the generalship of the professors in the educational zone of the theatre of economic warfare. The author, however, is of opinion that the drawing up of the curricula of engineering studies is not a matter that should be left entirely in the hands of the teaching profession; he ventures to suggest that it is one which requires to be carefully investigated by a Committee, the members of which should be drawn from the three classes, employers, engineers, and teachers, who should all act together, if the true interests of our industries are to be properly protected in all its aspects. Naturally, the most suitable body to deal with a question of this kind would be a General Engineering Council, did it exist. Finally, the author fully appreciates, as Mr. Denton has stated, that the British engineer is second to none. However, the author cannot be blind to the fact that in his wanderings over the face of the globe—and he has seen a great many parts of the world—he has found that engineers in foreign countries were occupying positions in the economic

sphere far superior, as a rule, to those occupied by our own engineers in this country. He has, rightly or wrongly, attributed this difference in the treatment of engineers, abroad and in this country, to the fact that the business education of the foreign engineer is better attended to than that of his British confrère. In consequence, in the author's opinion, the widening of the basis of the education of the engineering student seemed to be a most important matter at the present time from every point of view, and one which required to be very thoroughly discussed in order that suitable remedies might be applied where found to be necessary. This fact it was that prompted the author to accept the invitation of the President to prepare a paper on the subject, although, being no longer in as close touch with the engineering profession as it was at one time his privilege to be, he quite recognizes that he was not in a position to do full justice to it, but he ventures to hope that the ventilation of the subject may bring benefits to the great profession in which the best years of the author's life have been spent.

# DISCUSSION ON "CARBON BRUSHES."*

## North Midland Centre, at Leeds, 14 January, 1919.

**Mr. R. H. Campion:** It has taken some of us many years to arrive at a few of the conclusions stated in the paper. I think it is over 12 years ago since I standardized all the dynamo brushes under my care, employing small brushes and aluminium holders with copper gauze flexibles, and I attained very satisfactory results. There was one machine, however, with an exceptionally heavy, stiff brush gear with flat broad brushes which ran remarkably well and we left that alone, and to this day it is still giving excellent results. Since turbo-dynamos have come into use I have been struck with the difference of opinion among the manufacturers of the dynamos. I know of one firm where three different departments recommend three different types of brushes, and I have come to the conclusion that they generally prefer customers to find out by experiment the most suitable brush, even after a long questionaire has been filled up giving all the details about the machine. I believe a good deal of the trouble that has arisen with brushes has been due to a very poor, inefficient, and cheap type of brush gear. This was adopted by one big manufacturer and copied by a good many more firms because they thought it was standardized and was no longer experimental. As a matter of fact I believe it was put on the market because it was cheap and easy to make. It would be interesting to know the author's definition of "sparkless," as I have been amused at various times, on seeing dynamos sparking, to be told "That is a harmless spark." A most interesting point is on page 199 where particulars are given of two sets of brushes supposed to be working at 40 amperes per square inch, which are shown to be really operating at 24 and 56 amperes per square inch. I think a good deal of our trouble is due to not paying sufficient attention to the bedding of the brushes, and I notice that the author asks that an intelligent use should be made of the spring balance. I have always found it necessary to make one's own spring balance if this is to be reliable. If more attention were paid to that, I think the unequal pressures which are obtained would be remedied. The author has also expressed an opinion on a matter which has been much discussed in the technical Press, namely, whether to cut the mica. I am glad he is in favour of doing so, mainly, I believe, because the mica causes trouble with the brushes; but we find on the whole that it does pay to cut the mica. I should like to know more about the partial vacuum under the brushes. One can quite conceive there is a suction action taking place, and probably it does cause a partial vacuum. With regard to grooves on slip-rings, do I understand that to mean flats, because apparently the manufacturer is not to be held responsible, although I believe the blame is usually put on him? To sum up, small narrow brushes are the best for engine-driven dynamos; for surface turbo-dynamos we must use a box-type brush, and for radial commutators something with a good spring.

**Mr. T. Carter:** It is necessary for the manufacturer to know as much as possible about the brushes he puts on his machines, and yet the matter of brush grades is often very casually treated even by those who should know better. Standardization is a complicated matter as regards carbon brushes, and the author rightly points out the insuperable difficulty of standardizing quality. Size is comparatively a simple matter, but one feels that to standardize size without quality will be to land the inexperienced user in greater difficulties than at present. Each maker's standard machine, having its own peculiarities, should be fitted with brushes of a grade selected by the maker; but if dealers are to stock standardized brushes, they will tend to keep one

* Paper by Mr. P. Hunter-Brown (see page 193).

or two grades only, which will be sold as "just as good as" those the user wishes to replace, with, quite likely, disastrous results. The very fact that each maker has his own shape and size of brush, just as he has his own shape and size of bearing, compels the user to come to the maker for spares, with the result that he gets the right thing each time. The Admiralty has standardized sizes of brushes, and also mentions a grade as a sort of standard of reference, and has had successful results, but these are due rather to the easy conditions specified as regards density and other factors than to any special merit in the standardization. Let standardization be achieved, by all means, if possible, but only after the broadest possible view of the whole subject has been taken. I think it is possible for each manufacturer of a standard line of machines to find at most two grades, and perhaps one grade only, which will suit, say, 80 or 85 per cent of his machines. There is, therefore, a more or less universal brush for each maker's requirements, but what has been said shows that it is not reasonable to expect a universal brush for all designs. The matter of contact drop is exceedingly important. I have come across a case where increased pressure on brushes actually reduced the commutator temperature, because the contact drop was so much smaller that the total commutator losses were reduced in spite of the increased friction loss. Such an effect is most easily producible, naturally, with brushes having a low friction coefficient. There is, I believe, a very considerable difference between the positive and negative contact drops, and I should like to ask which is the larger of the two, and by how much the two drops differ from each other. I recently came across a dynamo with graphitic brushes where the negative brushes heated considerably more than those on the other pole. The matter was complicated by the swelling of the graphitic brushes—a feature not to be lost sight of in designing brush holders—which caused them to stick one by one in the boxes and so overload those which remained free, until all were more or less stuck. Curiously enough, the negative brushes which, on the quasi-electrolytic theory, should have worn more than the others, actually wore very much less, and there were other altogether unusual features. Unfortunately it is usually impossible to make the elaborate experiments necessary to prove exactly what is happening in such a case, and one has to treat the difficulty more or less empirically. I came across a case years ago which also was never satisfactorily explained, where a graphitic brush was tried, to improve commutation on a dynamo, but could not be used because it converted a previously normal machine into one hopelessly under-compounded, almost as though the brush deposited a semi-insulating skin on the commutator. If the author has had a similar experience, his comment would be most valuable. The one thing to aim at in the design of brush gear is the prevention of chattering of the brushes. The author has very fully stated the necessary conditions as regards brush holders, but I am inclined to think that the holders should be set even less than $\frac{1}{8}$ inch away from the commutator, say just far enough away to insert the emery or carborundum cloth for bedding the brushes, which would mean about 0·05 inch only. The importance of the insulated brush top in cases where there is vibration cannot be overestimated, as it prevents the pressure finger from digging into the brush, which is mainly a result of current passing between the brush and the finger. In fact, if the whole of the brush box could be insulated from the brush in such circumstances, much of the difficulty would probably disappear. Again, loose brushes imply chattering, and chattering sooner or later leads to a mechanical break up of the brush, with disintegration of the flexible connection and other well-known results. Circulating currents, which are no doubt generally local and confined to the brush contact, but may also be set up between sets of brushes of the same polarity in lap-wound dynamos insufficiently equalized, generally indicate their presence by well-defined markings on the brush contact-surface. Parts of the brush will appear bright, and parts will be dull, and frequently bright bands are seen, corresponding in width to the width of a copper segment on the commutator, and separated by narrow dull strips of the same width as the mica between the segments. Apparently as the brush periodically comes into a certain relation to the segments, circulating currents occur which by their reiterated action produce these definite marks, other positions of the segments tending, it would seem, to give normal results. The removal of the circulating currents, due to the design of the machine as they are, is frequently a difficult matter, and, if bad commutation is taking place, the simplest remedy is usually to select a different sort of brush. I should like to ask what the maximum volts of a machine using a copper graphite (mostly copper) brush should be. I have found difficulty, even with interpoles, in a plating dynamo giving 15 volts, and I am inclined to put the limit at about 10 volts to be safe. I should also like to refer to the excessive grooving of the commutator copper which occasionally occurs with pure graphite brushes, and to ask what is the cause and what is the remedy. The subject of mica grooving is one for endless debate. A collection of opinions got together casually will produce most contradictory statements. I much prefer not to groove mica, but to use a brush sufficiently abrasive to keep it down. If mica tends to come up in a new machine, persistent scouring with fine carborundum cloth—emery is no good for the purpose—for two or three weeks will often entirely cure the trouble, and only if it should persist in spite of everything is it necessary to try different brushes or, as a last resort, to groove the mica. In any case, the grooving if well and cleanly done need not be more than $1/32$ inch deep, as the prevention of wear it ensures will mean that the copper will disappear only very slowly, and the mica need not be re-grooved for a long time. Deeper grooving means the provision of a lodging place for carbon dust, and as it is usually impossible to keep the commutator surface entirely free from grease, a conducting adhesive paste is formed which may eventually lead to serious trouble. I should go farther than the author and say that on no account must lubricant ever be used on a commutator. If brushes are noisy, they should be changed for others

which will run more quietly, as lubricant usually effects only a temporary cure and, if the commutator runs hot, is very apt to soak into the brush and spoil it. Paraffin wax would appear to be one of the safest lubricants, if the user is determined to try one, but even it has its dangers. I have occasionally found only one or two brushes picking copper on a machine, and merely to clean the contact surface is generally not a cure. But if the picking is due to the commutator being new and not having a good skin developed on it, this isolated picking can frequently be cured merely by taking a new brush out of stock and substituting it for the brush which has been giving trouble. It would almost appear as if the copper particles were carried some small distance into the brush, thus altering it for a little of its length behind the contact surface, so that cleaning still leaves a surface of too low a resistance, which tends to produce abnormal current density in that same brush again, so causing picking to continue; whereas if a new brush be put in and the commutator has begun to get a new skin on it, the tendency to start picking has disappeared. Can the author suggest any explanation of the fact that copper picking is promoted by lack of perfect contact between brush and commutator? Is it because the quasi-electrolytic action is increased by the greater contact drop which occurs as a result of the poorer contact? His remarks about the difficult conditions caused by the attendant will be read with great sympathy, I am sure, by all manufacturers. Finally I would say that in my opinion it is not advisable to try to get comparative technical data about different brush grades under actual working conditions on a fully-excited, fully-loaded dynamo or motor, because then other conditions are operating which complicate the interpretation of the results and render them valueless. What we want are comparative data stating generally the difference between brush grades as measured under very simple and clearly defined conditions. Then, knowing the constants of any particular brush, one can calculate the nominal loss due to contact drop and friction, and from that figure find a design constant for one's own machines which will enable losses to be translated into temperature rise. The design constant thus obtained will include all the peculiarities of the line of machines, such as the effect of pole-tip shape, circulating currents, etc., and thus the simple data given by the brush maker, obtained on short-circuited commutators or plain slip-rings altogether detached from any machine, can be immediately used by any designer, instead of having to have sorted out from them the effects of some probably unknown commutating conditions of the experimental machine. Here, as elsewhere, the essence of success in design is discretion.

**Mr. W. H. Brown**: I must differ from the last speaker, for, as I have so many types of machines to deal with, I should very much welcome some form of standardization or interchangeability which would enable us to decrease the large number of different brushes I am now compelled to use. I have often wondered whether it would not be possible for the author's firm, in conjunction with dynamo and motor builders, to bring out a few types of holders and brushes which would meet all requirements for ordinary industrial conditions. But possibly nothing really effective will be done until our engineering firms begin to manufacture in the true sense of that word, and cease to "build" and "make" electrical machinery. I should here like to make an earnest appeal that the question of interchangeability of electrical machines should be very seriously considered, because I feel quite certain that if something on these lines could be done it would cheapen the cost of production very much, and machines could be sold to customers at prices far below the present-day values, with advantage to both the maker and the user. Notwithstanding many years of experience in the use of commutator and brush gear generally, we do not seem to have come quite to the end of progress in the art of designing brushes, for on page 200 the author says—under "General"—that "the ultimate test as to suitability must be made on the machine itself," to which I should like to add "by the user"; for I am afraid it is scarcely practicable for the maker to do it before the machine leaves his works. On page 194 the author mentions that if a small proportion of copper is added, the effect is actually to increase the resistance; I should be glad to know the precise reason for this. Again on page 197 he gives a table showing the thermal conductivity of different types of brushes; does the electrical conductivity also follow the same course? The question of grooving micas is very interesting, and often causes much controversy. My own practice is very simple but effective: if a machine runs well with full micas, we let it go, but if flats appear, we groove the micas about 1/32 inch or so, with the result that in practically every case the commutation and behaviour of the machine is greatly improved. In a few cases we have had to fit a different class of brush, though I am glad to say that this has not often occurred.

**Mr. J. H. Shaw**: I want to put in a plea for standardization. If, as the author informs us, it is impossible to standardize qualities of brushes it is all the more essential that some standardization of the sizes of the brushes, of the pigtails, and of the tops, be taken in hand at once, after which some standardization of qualities is bound to follow. The undertaking in which I am interested has 1,370 electric motors out on hire, and I do not know how many grades and different sizes of brushes have to be carried, but the space devoted to carbon brushes in the stores is simply amazing. With regard to the undercutting of commutators, we find that on large machines such as rotary converters, boosters, etc., it is essential to cut down the mica below the face of the commutator. This gives more satisfactory running, enables the machine to run longer between cleaning, and in general gives better commutation.

**Mr. H. W. Walker**: I think it is a foregone conclusion that the box-type brush holder is the best to use for industrial motors. I should like to endorse Mr. Brown's views with regard to the standardization of brushes. Personally I think they ought to be standardized with regard to section and length. My employers have 1,500 motors on hire, and one can imagine the trouble they have in sending out to faults, which are very numerous as far as brushes are concerned. I

believe we have 300 types of brushes. Wherever a brush fault occurs it means a double journey for the motor inspector. On those grounds I think it is essential to standardize one, two, or three types of brushes in size only.

**Dr. S. F. Barclay** (*communicated*): It is to be regretted that the author deals only with the staggering of brushes with machines having an even number of pairs of poles. When the number of pairs of poles is uneven, if the brush arms are staggered in pairs as shown in the lower diagram of Fig. 7, there will be unequal wear of the commutator, since all parts have not the same number of brushes in contact. In such cases it becomes a question as to whether to correct the electrolytic action by staggering the brush arms in pairs will not be more than offset by the disadvantage of having more wear at some parts of the commutator than at other parts, and it would be interesting to hear the author's views on this point. My own experience does not agree with the author's that the Admiralty gunmetal is an excellent material to use for slip-rings. I have carried out a considerable number of experiments with different bronzes for slip-rings, and I find that a hard bell-metal is decidedly superior to the Admiralty mixture. The author makes no reference to the wear of slip-rings with regard to their position on the shaft. I have found in general that when the slip-rings are carried on an extension of the motor shaft, exterior to the bearing, the wear is greater than when the rings are mounted between the bearings. In particular I have noticed in a number of cases where three slip-rings have been carried on an extension of the motor shaft, that when considerable wear has taken place on the outermost, the innermost ring has hardly been touched and the state of wear of the middle ring has been intermediate between the two. This experience has shown the great importance, particularly for high-speed work, of having a rigid motor shaft and, when possible, the rings located between the bearings. In recent years there has been a great deal of discussion among engineers and metallurgists as to what is meant by "hardness." The word, without qualification, conveys but little meaning, since a material that is relatively hard in one respect may be relatively soft in another. For example, steel containing about 12 per cent manganese is so hard in one respect that it cannot be machined, and so soft in another respect that it has a very low elastic limit. I quite agree with the author in differentiating between abrasiveness and hardness, but when using the latter word it ought to be made clear in what respect it is employed. Thus in speaking of the hardness of a carbon brush, one should say hardness to deformation, hardness to abrasion, or hardness to wear, etc., since it does not at all follow that a brush which is hard in one respect is hard in all respects.

**Mr. P. Hunter-Brown** (*in reply*): Mr. Campion has asked for a definition of the term "sparkless." I think we all use the word in a more of less relative sense at times, and the exact interpretation intended cannot be determined without reference to the context. Personally, when using the word even in its strictest sense, I do not mean more than that no sparking is visible, although minute sparking may be and probably is taking place underneath the brush.

Various speakers have referred to the vexed question whether mica should or should not be recessed, and the subject has also been discussed at considerable length recently in the technical Press. The various views that have been expressed confirm me in my opinion that the success or otherwise of running with recessed mica depends very much upon the views regarding this subject of the engineer responsible for the plant. One who is enthusiastically in favour of it will see that the work is carried out with the precision that is essential to success, and in general will, I think, be able to show an exceptionally favourable cost sheet for brush and commutator maintenance. On the other hand, I know of few things more certainly doomed to failure than an experiment with recessed mica carried out by one who has no faith in the practice. With regard to ordinary industrial motors, I think Mr. Brown's method a very good one; if the machine runs satisfactorily with flush mica he leaves it thus. If trouble develops and the symptoms suggest that the mica is the cause, he recesses it.

Mr. Carter opened his remarks by referring to the question of quality, and suggested that each manufacturer of a standard line of machines can probably use a single grade on some 85 per cent of those machines. The grade selected by one manufacturer, after trial of many, will in all probability, however, be different from the one selected by another manufacturer of a similar line of machines, and this fact emphasizes the points made by Mr. Carter on this subject. An interesting case was mentioned by the same speaker, of a dynamo which became hopelessly undercompounded when the grade of brush was changed. The voltage of the machine was not stated. With a very low-voltage plating dynamo, the heavy drop in the compound curve might be directly attributable to a high contact drop at the brushes, but with a machine of, say, 110 volts or upwards this is obviously impossible. Assuming that a brush were obtainable with a sufficiently steep and sufficiently high contact-drop curve, the extra $I^2R$ loss at the brushes would produce an enormous commutator temperature-rise. I have met one or two somewhat similar instances, and have attributed the undercompounding to the demagnetizing action of the current in the short-circuited coil, the value of which might be radically altered by a change in brush quality. Mr. Carter suggests the use of a box completely insulated from the brush. This would overcome certain difficulties, but would, I am afraid, introduce greater, as the brush would then be thermally insulated as well as electrically insulated from the holder, with the result that under severe operating conditions a destructive temperature rise of the brush would occur.

With regard to a suitable quality of brush for very low-voltage dynamos, I do not know what proportion of copper Mr. Carter had in mind when referring to this subject, but assuming the brush to contain 75 per cent or more of copper, I should not expect it to be suitable for a machine designed to give more than about 10 volts. It is not easy to explain why a single

brush sometimes persists in copper picking (when once it has acquired the bad habit), even after it has been rebedded and apparently all the copper removed from its contact surface. Possibly specks of copper may have been left embedded in the surface, or possibly when the brush first began copper picking it carried exceptionally heavy currents in consequence, which produced a local temperature-rise sufficient to graphitize the material partially. In either case the resistance of that individual brush would be lowered and the conditions rendered favourable for copper picking to recur.

Mr. Brown and other speakers referred to the multiplicity of brush-holder designs. At the present time a committee of dynamo and motor manufacturers is considering the problem of standardizing brush holders, and if their efforts meet with success this will no doubt afford a substantial measure of relief in the desired direction. Generally speaking, brushes of high electrical conductivity also possess high thermal conductivity, but there is not such a definite relation between electrical and thermal conductivity as exists in the case of metals. On the other hand so far as I have been able to obtain data on the subject, the electrical conductivity of both graphitic and non-graphitic brushes increases with an increase in temperature. The thermal conductivity of graphite decreases with an increase in temperature, whilst that of non-graphitic carbon increases. The introduction of copper also has a disturbing influence upon the relationship. The copper graphite brush referred to in Fig. 4 may be regarded as the natural graphite brush referred to in the same figure with the introduction of a preponderating proportion of metal. The electrical conductivity is thereby increased a hundred-fold, but the thermal conductivity is not greatly affected.

Dr. Barclay refers to the difficulty which arises in connection with staggering brushes when the machine has an odd number of pairs of poles. In such cases, as he points out, it becomes a choice of evils, and my own opinion is that the lesser is to arrange the brushes so that different tracks on the commutator are not swept by a widely different number of brushes; that is to say, with a 6-pole machine I would arrange 4 rows, as shown in the lower diagram of Fig. 7, the fifth row as the top row and the sixth row as the bottom row. We should then avoid having part of the commutator swept by two brushes only, and at the same time no part of the commutator would be swept by brushes of one polarity only. With regard to the indefinite way in which the term "hardness" is used, I conclude that Dr. Barclay's criticism is directed to what is common practice and not to my paper, as the latter specifically refers to hardness to deformation. A reference in the same communication to the great difference in the rate of wear experienced with overhung slip-rings and rings located between bearings certainly underlines in a very emphatic manner the remarks I have made upon the difficulty of maintaining uninterrupted contact between brush and ring and the result to be expected when contact is imperfect. If my paper and the discussion that has followed lead only to a fuller realization of the mere mechanical problem involved in operating carbon brushes, the effort will not have been made in vain.

## Scottish Centre, at Glasgow, 11 February, 1919.

**Mr. J. Prentice:** I should have preferred to see the author deal with the question of standardization with even greater decisiveness. The old adage—"Of the making of books there is no end"—applies here and, I think, without the same justification. The modern machine designer, having at his command commutating poles, compensating windings, and, from this time onwards we hope, uniform magnetic and electrical quality of the various materials used, is not justified in calling for an interminable range of brush grades and sizes. The author refers to machines built at the same time and intended to be duplicate requiring different grades of brushes to obtain satisfactory results. Personally, should any manufacturer put forward a proposal of this kind in connection with present-day machines, I should have no hesitation in turning it down, and would invite him to find a more satisfactory solution of the difficulty. To indicate the need for standardization of brushes (and of machines), at one of the works with which I am associated we are carrying spares for over 100 different sizes and qualities of brushes. For use on rotary converters, etc., the metal graphitic brush with box-type holder and adjustable-tension spring has many advantages. Compared with the sheet copper or gauze brush backed with a phosphor-bronze spring carried in a rigid type holder, it requires less skilled attention, is easier to adjust, and the wear of the slip-rings is much less. Some time ago I had a 750-kw. 220-volt rotary converter fitted with impregnated copper-foil brushes. These were carried in holders capable of tension adjustment, hold-off catches to facilitate cleaning, etc., being provided. The results obtained were satisfactory. The manufacturers guaranteed an improvement in efficiency of $\frac{1}{2}$ per cent with this type of brush as compared with the metal graphitic. The capitalized value of this additional $\frac{1}{2}$ per cent during the life of the rotary converter represents a considerable sum. For rotary converters in general, however, I favour the metal graphitic type. As an example of what is possible with this brush, I have a case of a 500-kw. 220-volt rotary converter which has run for the past four years at an average load of 75 per cent, including frequent overloads up to 25 per cent. The approximate number of running hours per annum is 6,400, and most of the original set of metal graphitic brushes (American make) are still in service. I fully agree with the author's remarks as to the desirability of brush boxes being deep and of cast metal, and also that the brushes should be a proper fit in the boxes. In this connection it should be kept in mind when arranging these clearances that certain types of brushes, including the soft graphitic,

swell considerably with increase of temperature. The method of fixing the copper tail to the brush should, as far as possible, be standardized, and the "tamping with metal dust" adopted by one of the leading brush manufacturers in this country is among the best. For general purposes I do not favour the plating of brushes. Frequently it is badly done and sooner or later portions peel off. Occasionally a new brush is slightly tight for the box, in which case one side at least of the plating has to be sacrificed and frequently what is left gets in the way.

**Mr. J. R. Cowie:** I agree that it is very desirable to have, say, three qualities of brushes to meet all cases, but as a practical man I know that this cannot be done. My records show two machines of absolutely similar design, built to the same order and running under practically similar conditions, but which have to be fitted with different grades of brushes in order to give the same results. If the brush that has proved satisfactory with one of these machines is fitted to the other machine the result is continual flatting, necessitating re-grinding of the commutator. I should like to point out that all commutator troubles are not due to brushes. I remember the case of a 250-kw. rotary converter where commutator trouble was removed by overhauling the amortisseur or starting bars in the pole faces. The machine was of the tap-starting variety and naturally the starting currents were severe. Another case in which the fault was with the machine was a 1,000-kw. motor-generator set in which the commutator only remained in a fit condition for some 8 or 10 weeks. This was put right by very careful pitching of the brush arms by taking the brush boxes off the arms and seeing that everything was thoroughly cleaned and properly bolted up. With reference to the author's remarks under the heading "Friction," our experience is that one of the weakest parts of brushes is the method whereby the leads are fixed to the brush. Some machine manufacturers insist on putting their own types of connections on to the manufacturer's leads. This has resulted in confusion, even when samples of parts to be replaced are sent direct to the brush people, and in one case during the war this almost shut down one of the biggest shipyards. Another point is that sufficient attention is not paid to the design of brush holders, first, in regard to stiffness, and secondly obtaining the maximum depth of wear from the brush. I remember one case where it was necessary to cut a $\frac{1}{2}$ inch length off before the brushes could be made to enter the boxes, and the springs were not long enough to follow the brush down to the slip-ring—in fact the length of the useful part of the brush was only $\frac{3}{8}$ inch—and as such brushes may cost anything up to 4s. each, from the user's point of view this requires very careful consideration. I agree with the author that sub-divided brushes are much more satisfactory from the running point of view than one big block of material. At the same time, one must remember that the machine manufacturer who uses sub-divided brushes is competing in an open market and the extra parts mean loss of money so far as he is concerned. All our specifications contain a clause which states:—"The brush-gear is to be of a type to be approved and it should be specially noted that owing to recent troubles we have experienced with brush-gear on machines, standard equipment might not be acceptable. A full description of the brush-gear offered should be sent with the tender." This practice is sometimes called in question. With such a clause in the specification due allowance can be made for the manufacturer who is turning out the best job. I can recall experiments on 500-kw. 500-volt and 220-volt rotary converters all by the same manufacturer, the experiment being then extended to a 250-kw. 110-volt machine. The problem was to reduce the dust nuisance from copper-carbon brushes and to minimize the expense of cleaning, as in some instances this cleaning meant four hours' work for a tradesman and labourer every Saturday afternoon. On the 500-volt machine a new grade of brush gave very satisfactory results. On the 220-volt machine, however, the powder trouble was again distinctly visible. On the 110-volt machine there was little improvement, not only so but the brushes melted away in the box holders and we have had to return to the old state of affairs. The current densities were 70 amperes, 90 amperes, and 75 amperes respectively, and the slip-rings were absolutely true and in first-class condition, having been turned up before experimental brushes were inserted. I also experienced another trouble with carbon brushes to which a small percentage of copper had been added. At one of our outlying stations a 500-kw. rotary converter flashed over from the face of the brushes to an adjacent slip-ring. On examination it was found that copper globules had formed in the faces of the brushes. We now know that this was probably due to the electrolytic action described by the author. Some little time afterwards another machine behaved in exactly the same manner, and this grade of brush is therefore no longer used on our system. One of the finest brushes for slip-ring work is of the copper variety, but will not run satisfactorily unless artificial lubrication is applied to the slip-rings. Other manufacturers have tried to make a material which will compete with this brush; one we tried ran very well for a number of weeks, then the flexible began to give trouble, and the brushes seized to the sides of the brush holders. The moment the flexible began to give trouble there was local heating such as the author has described. I think that both brush manufacturers and machine manufacturers ought to consider the position of the engineer on a big system who is running hundreds of machines, many of them duplicates, and yet hardly any duplicates so far as the brushes are concerned. There would seem to be two reasons for this: (1) the unnecessary utilization of copper-carbon in order to get decimal increases in efficiency; (2) the use of copper-carbon brushes in order to reduce the number of brush holders supplied with a machine. Also, where the maximum possible number of brush holders have been fitted in the available space there is no continuity of policy. To overcome these defects, I have in my office a list which shows every machine on the system, the number of brushes, grade, size, etc., and from this list we have adjusted box details. Where necessary we have brought the maximum number of machines to one grade of brush, thereby cutting down the amount of

spare material which our Stores Department require to carry; not only so, but instead of ordering brushes, etc., from the manufacturers in dozens we are now able to order in gross lots and obtain spares at a much cheaper price. From the same list we find that various manufacturers use the same grade of brush and that perhaps there is $\frac{1}{8}$ inch, or less, difference in the sizes of brushes. Is it not possible for men like the author to get manufacturers together and standardize practice throughout the country?

**Mr. J. J. Inglis:** I quite agree with most of what the author says in his paper. I have always felt that brush or carbon makers have been badly abused by the machine manufacturers. Bad design and careless workmanship are undoubtedly the cause of most trouble in generators and motors. I have found it necessary to make a standard type of brush gear and replace most of the gear supplied by some makers. We want to have as few parts as possible with brush gear, and stampings used for the actual brush holder should always be avoided. I think it is always necessary in selecting brushes to class the machines in different groups. By grouping we can cut down the number of grades required. With turbo-generators I find that two grades are quite sufficient; with continuous-running motors for all speeds three grades; reversing direct-current motors two grades. My experience has been that if one cannot get sparkless commutation with these grades, the machine ought to be examined and put right. The author refers to the use of a spring balance for brushes. That sounds very nice and very often shows up the fault of the carbon makers. For instance, I remember about eight years ago having a lot of trouble with a turbo-generator. Quite a number of different grades of brushes were fitted on that machine. We latterly adopted one very soft graphite brush. They were set by spring balance, but as we did not get perfect commutation it was suggested that the brushes be set by temperature. Before doing so the brush temperatures were taken after the brushes had been set with the spring balance, and the temperatures differed by as much as 25 degrees F. The brushes were taken out and were tested by a millivoltmeter. It was then discovered that many of the flexibles were making very bad connection with the carbon. The machine was kept in service for about six years but always required a great deal of attention every few hours. We latterly decided to re-wind the armature. This was done and we found that quite a number of the connections in the armature windings were very badly soldered. After re-winding, the machine was put on full load and has required no further attention. Three different grades of brushes have since been tried on that machine and they all give equally good results. I have found exactly the same thing with many motors; consequently I always look for trouble in the design of the machine, either electrically or mechanically. The pressures given by the author work out very well in practice. That again depends upon the quality of grade of the brush fitted to the machine. I do not agree with him in his system of bedding brushes. While it might be possible with some generators and a few motors to bed down carefully with glass paper and allow the machines to run light for some time, in the majority of cases this cannot be done. In many cases on charging machines and cranes it is not possible to grind down the brushes when the machine is running, or even to get at them with two hands to bed them down. It is good practice not to change all the brushes at once, but fit, say, half at a time, allowing them to bed themselves down before the others are taken out. The author mentions that an insulating material should be fixed on the top of the brush, where necessary, to prevent the current going along the spring or clamp holding down the brush. I have very often found fibre give trouble, especially in cases where there is a considerable rise in temperature on the machine. The fibre usually works loose and falls out. If heavy flexible conductors are fitted on properly I do not see that there is any necessity for insulating material. The standardization of brushes should be taken up very strongly with the motor makers. There is no reason why the number of brushes cannot be kept down to a minimum if manufacturers will agree to certain widths, lengths, and thicknesses of brushes. It would be a good plan if the carbon manufacturers would get together and arrange to classify their corresponding grades in a similar manner; class "A" grade, for example, being the same for each maker, and class "S" also, and so on. At the present time the buyer has great difficulty in knowing exactly which grades of different makers correspond to each other. I also think that drawings might be substituted for the samples now sent.

**Mr. R. B. Mitchell:** I should like to ask the author one or two questions. Will he state what he considers to be sufficient equipment for a laboratory for testing brushes? On page 197 he refers to the Shore sclerescope; where can I find a description of this appliance and who are the manufacturers? As to standardization, I agree with other speakers that this has been very much neglected. I have two instances here which prove that. In 1914 a large works in this city used 120 classes of brushes, and in another instance 57 different sizes were used. By careful standardization on the part of the engineers the number of sizes in the latter case was reduced to two. I think that, particularly with small motors, one or two sizes should be used almost invariably.

**Mr. W. H. Flood:** The carbon brush when first introduced was applied in a very crude form and I fear its actual function as a commutating device never entered into the designer's calculations. Copper brushes were removed from the holders of existing machines and replaced by carbon ones, and, if sparkless commutation resulted from the change, the dynamo attendant was left to make the best of things and decide for himself the best running position and pressure required to ensure the best results. In some cases the change proved satisfactory, but in others trouble soon presented itself and copper brushes were again resorted to. This unsatisfactory state of affairs was brought about by the want of a better knowledge of the application of carbon as a collector, and not until the subject was taken up seriously by the designers did we get anything approaching satisfactory results.

In many instances the type of brush was quite satisfactory but the brush holders were found to be defective and soon gave trouble through heating, which having once taken place caused the brush gear as a whole to collapse, because the springs lost their tension and no amount of care could ensure satisfactory running, especially at full load, after this had occurred. With a carefully selected brush which has been found to give satisfactory results on the test bed, one would think that a machine would run quite well when set to work on ordinary duty, but owing to the varying conditions under which most machines have to work, a change of brush is often found necessary before satisfactory and continuous running can be ensured. To my mind, present troubles are mainly due to the imperfect design of the brush holders, as each maker seems to have his own idea and we find quite opposite designs used on machines of the same output and speed and with commutators running at the same peripheral speed. From the data given by the author we appear to have arrived at a stage when the carbon brushes have reached a high state of perfection, and it is now up to the dynamo designers to do something on their side, and I would suggest the standardization of armatures and proportions of commutators for all sizes of machines listed to run at standard speeds. This would materially assist in decreasing the number of types of brushes. When we get trouble to-day through brushes working badly we are compelled to appeal to the brush-makers, who after viewing the machine running on load invariably suggest a different grade of brush from that supplied by the machine makers, which in some cases means a big expense for what may be called an experiment. Personally I should like to see the number of grades reduced to about four, including a special grade for use on slip-rings. It is interesting to hear that Admiralty gunmetal has been found to be the most satisfactory metal for slip-rings, as I was under the impression that the makers had a special mixture of bronze for this work. The partial vacuum sometimes produced under a brush would, I think, only appear in the laboratory, as in practice we do not find it possible to maintain such a fine degree of bedding and adjustment to obtain this effect. The undercutting of mica has its advantages, but where a machine is running quite satisfactorily, I do not believe in undercutting merely because it is the fashion, but I find there is a tendency to-day to do this when an armature comes in for repairs. The staggering of brushes is a very important point, but some makers of small machines do not allow sufficient width of commutator to carry this out satisfactorily. As the author states, and rightly too, the brushes and brush gear form the weakest link, and at the same time constitute the most vital part in the chain of conversion of the commutating machine. This requires very special attention, and as we now appear to know the true value of carbon brushes of various makes and grades, I think it is up to the designers to produce the correct form of brush holder. I have during over 20 years' experience found the brush holder very largely at fault. The British Admiralty have standardized the sizes and grades of brushes within limits and have also moved in the direction of a standard brush holder, and I must say the results obtained are quite satisfactory. Sparking troubles have been reduced if not eliminated altogether, and the brush holders now used are of good design, working on a standard principle.

**Mr. A. P. Robertson:** There are a number of things in the paper which will be very useful to me. For instance, at the end of page 198 the author refers to connections. That is a point we have had a lot of trouble with, especially in pin-type connections. The connections are put in with a sort of paste, and after getting heated the paste comes out. We have not had any serious accidents yet, but it might lead to a bad flash-over. I think the best type of connection is the screw type, but care must be taken that the nut is not screwed in too tightly. We have some types where flexibles are put on to a shoe and put over the carbon brushes, being fixed with one bolt. These are quite satisfactory and the flexibles can be renewed easily. The only bad point is that the flexibles are soldered on to the shoe piece. Pinching is the best method, but it is a most difficult matter to make a satisfactory contact—sometimes it is good and sometimes it is bad. So long as the brushes are attended to regularly, there is no trouble, but when they get overheated the soldered piece may come out, and it is a common thing to have drops of solder with that type of connection. There is also the riveted type, which holds all right so long as there are plenty of brushes and not much current flowing. It is very difficult to get a satisfactory rivet. Further on the author states that he recommends a bone cleaner for cleaning segments. I think it is the best plan to reduce mica wherever possible. We use a hard bristle brush and the commutators are cleaned out on every possible occasion—in our substations every night, or whenever the machines are shut down—and there is no trouble so long as they are kept clean. The only trouble is that in order to prevent the noise the attendants put in more wax as lubrication than they ought to do. That sticks between the segments, but if they are cleaned out every night with a stiff brush there is no trouble. In regard to lubrication, we used to boil the brushes for two or three hours in paraffin wax. It was quite satisfactory and we boiled them every six or seven weeks. It was easily done by the engineer on night shift. With regard to standardization, I think everyone is agreed that the number of different types of brushes on a big system which has a large number of motors is excessive. Every motor seems to have a different type of brush. There is only a very small difference. I have known a case where they kept a big size and filed them down to suit the smaller sizes. That is not a good plan, but it is often done. It is remarkable how small are the differences in the sizes of brushes and connections.

**Mr. A. Page:** I should like to hear the author's opinion of oscillating devices such as are generally fitted to rotary converters, also his experience of radial commutators. In the table on page 196 the contact drop on the positive brush is markedly greater than on the negative brush; it would be interesting

to have the author's explanation as to why this difference exists. The self-lubricating properties of the graphite brush are referred to, and the author tells us to avoid the use of any lubricant, but carbon brushes may have to be helped out in that way, and I have found there is nothing better than a piece of good quality paraffin wax rubbed on the commutator occasionally. It is stated that copper plating is sometimes a necessity with certain types of connections. As the plating generally peels off, its usefulness is not very apparent. The reference to electrolytic action does not carry conviction. I do not see how this can take place without an electrolyte, and air or a vacuum could hardly be classed as such. I trust there will be two developments as the result of the vast amount of work the author has put into the paper: first, if complete standardization is impossible, that at least a fair degree of standardization will be attained; and secondly, that the barbarous methods in vogue to-day on the part of many men who are responsible for the upkeep of electrical machinery will be departed from. I think it would be greatly to the benefit of all owners of electrical plant if a copy of a paper such as this were put in the hands of every man in charge of motors and generators.

**Mr. W. B. Hird:** I am moved to say a word on brush standardization by the fact that so many of the speakers, all large users of machinery, have spoken of standardization in a way which appears to put the whole blame for the fact that there is no standard size of brush on the manufacturers. I should not like to be accused of being an opponent of standardization in any form, but it is only right that it should be recognized that in such a matter as standard brushes the whole of the trouble and expense of effecting a change will fall on the manufacturer and all the advantages will be to the user. The firm with which I am connected have made only one type of brush holder and one standard size of brush for all normal cases for many years; others have, I believe, worked on similar lines, and if anyone finds himself obliged to stock 120 different sizes of brushes, as one speaker said he had to do, it surely shows a great disregard for standardization in his purchasing department. Many manufacturers having already standardized in their own lines; to ask them to adopt a uniform practice will mean changes of pattern and will entail on most, if not all, of them a considerable hardship. To the user, however, it will be nothing but pure gain. In those circumstances is it fair of him to put all the blame on the manufacturer, and should he not rather set his own house in order and, by purchasing not solely on price but with a view to keeping his parts standard, show at any rate that the question appeals to him sufficiently to induce him to make some sacrifice to help standardization? Another point raised is the question of undercutting the mica of commutators. I am somewhat disappointed at not having had a more definite ruling on this point. It would seem, however, that each case should be dealt with on its merits. Mica should be cut down only in those cases where it distinctly shows a tendency to get above the flush; in all other cases the danger of short-circuits through dirt in the grooves should be avoided by leaving the mica alone. The difficulty of formulating a general rule is well shown by the attitude of the different insurance companies who, being responsible for the upkeep of large numbers of machines of all sizes and makes, quickly obtain very valuable experience of the results of such a change. For a time they all issued very conflicting orders—first that all commutators should have the mica cut down, then that none should be so treated—but they have now, I believe, for the most part settled down to leaving their inspectors to deal with each case on its merits.

**Mr. P. Hunter-Brown** (*in reply*): Great interest in the question of standardization has been shown and many speakers both at this and other meetings have dwelt upon the subject. As mentioned at the Leeds discussion (see page 257) a great effort is actually being made at the present time by a number of the leading machine manufacturers to standardize holders. If this be carried through successfully it will effect a very large reduction in the number of sizes and designs used for future machines and, where desired, it may be possible in many instances to fit the new holders on existing machines.

I agree with Mr. Cowie that the brush manufacturer should supply brushes ready to be fitted to the machine so that no terminals or other fittings have to be added by the machine manufacturers. This tends to prevent confusion and delay and, moreover, places the responsibility for the complete brush in the proper quarter. With regard to the size of the brush, it is of course true that the brush gear is cheaper if a few large brushes are used instead of a larger number of brushes of moderate size, but I am convinced that the manufacturer who adopts the latter course is more than compensated for his extra outlay by the improvement in performance of his machine. His ability to secure orders depends not only upon his cost of production, but also upon the reputation he has established, and there is a definite connection between this and the design of the brush gear.

Graphite brushes may no doubt be used with advantage in many instances on slip-rings. They cause less dust than any type of copper-graphite, and what dust is produced is more harmless in character. When contemplating a change from copper-graphite to pure graphite on an existing machine, it is necessary to consider carefully the radiating surface of the rings and not to be guided by the current density in the brushes alone, a point that is sometimes overlooked, with very natural consequences. I do not consider the universal adoption of graphite brushes for slip-rings to be practicable, however, even for machines still in the designing office, and in some instances an appreciable loss of efficiency would be entailed.

Mr. Inglis has offered a useful suggestion with regard to replacing worn-out brushes on a machine. Some motors are very inaccessible, due either to the design of the motor case or to the position in which the motor is fixed. Where a large number of such motors with commutators of the same diameter are in use, a wooden dummy commutator of correct diameter can be fixed in some convenient position on the wall or bench with

a brush holder mounted in correct relation to it. The brushes can then be bedded on this device to the correct radius and angle. This arrangement has proved very useful, for instance, in bedding down traction brushes. In the case of metallic brushes a great deal of the labour involved in bedding may be avoided by ordering the brushes from the maker already curved on the contact surface, even if the radius can only be specified approximately. The amount of time and trouble it is worth while to expend in perfectly bedding brushes doubtless depends to some extent upon the responsibility devolving upon the machine in question, and the conditions under which it is operating, but, generally speaking, it is time very well spent. It is a mistake to assume that to run badly-bedded brushes merely means that for the first few hours a little sparking or overheating may occur. If the conditions are severe the brushes may thereby be prevented from ever working up to a satisfactory surface and rapid wear, perhaps accompanied by sparking, may be the result. Regarding the use of insulated brush tops, it is true, as Mr. Inglis mentions, that fibre in certain cases is apt to give trouble by working loose and falling out, and for this reason the growing practice of using an insulating material which can be moulded on to the brush in a plastic condition and made virtually integral therewith, is greatly to be preferred.

Referring to Mr. Mitchell's queries, it is not suggested that it is worth while for any user to install the necessary apparatus for testing brushes. Indeed, the expense of this, which is extremely heavy, should properly be borne by the brush manufacturer and not by the user. It is not generally known what a complex problem successful brush manufacture presents, and a very extensive laboratory equipment is required for making tests upon the raw materials and at various stages during manufacture, as well as upon the finished brushes. Such equipment to be really efficient must include apparatus for carrying out chemical, microscopic, metallurgical, electrical, and physical tests, and to do justice to such an extensive plant would require a paper to itself. The Shore scleroscope is an instrument by means of which a small diamond-faced cylindrical hammer is caused to drop through a graduated glass tube on to the specimen under test. The height of the rebound of the hammer up the glass tube is a measure of the hardness of the specimen.

The types of connection that require the brush to be copper plated are a purely soldered connection between the flexible cord and brush, and also a connection formed by pressing the flexible cord against the side of the brush, either by means of a bolt or rivet. A metal shoe, as described by Mr. Robertson, is another alternative form of connection but, as he points out, it is a difficult matter to make a satisfactory connection between the shoe and the flexible cord, and moreover all bolts and rivets are open to the objection that they increase the inertia of the brush. The ideal connection should be free from bolts, rivets, solder, and, for the reason stated by Mr. Page, should preferably not even be dependent upon copper plating. Boiling brushes in wax or oil certainly improves their lubricating qualities, but the practice cannot be described as anything but crude. For the first few days there is too much lubricant and at a latter stage, when the lubricant is becoming exhausted, there is too little. The practice was very much in vogue in the United States some years ago, but of recent years has met with strong condemnation in that country.

I should have been glad to have heard Mr. Page's own opinion of oscillators. There is great diversity of opinion on this subject. Certainly some of the most perfect commutators and slip-rings I have ever seen have been on machines fitted with this device. On the other hand, I have seen a very great improvement effected in the running of a machine by putting the oscillator out of action. If the ring and commutator face do not remain in perfect condition, the oscillator tends to prevent uniform contact between brush and collector. It is important that the clearance in the width of the brush be not more than is just sufficient to ensure freedom of movement in the holder. My experience of radial commutators has been most satisfactory. If the commutator is slightly out of truth, or slightly out of balance, the brushes are relieved of the pounding action to which they would be subjected on an ordinary high-speed cylindrical commutator. One 1,700-ampere machine, which I had an opportunity of watching particularly closely, ran with an absolute minimum of attention, and the first set of brushes lasted more than two years although the machine was running on full load for something like 100 hours per week. My paper makes no attempt to offer a scientific explanation of the quasi-electrolytic effect, but merely emphasizes the existence, under the negative brush only, of a phenomenon which is quite distinct from abrasion and burning action. An excellent example of this effect is often to be seen in alternator field rings. Frequently it will be found that the negative ring wears very much faster than the positive. If the polarity is reversed every few weeks, not only will the two rings wear evenly but the total wear will be materially reduced, because during the period a ring is positive it works up to a fine polished surface which is not destroyed until the curent has been reversed for some considerable time.

# DISCUSSION ON

## "THE USE OF HIGH-PRESSURE AND HIGH-TEMPERATURE STEAM IN LARGE POWER STATIONS." *

North-Eastern Centre, at Newcastle, 9 December, 1918.

**Mr. J. W. Jackson:** There are a few points on which I should like to have some further information. In Schedule 2, col. 1, the steam consumption of a turbine per kilowatt-hour is given as 9·46 lb. for 215 lb. pressure, 300 degrees F. superheat, 0·9 inch vacuum. I consider this figure to be extremely low, in fact very much lower than anything we have met with as a commercial proposition, except on the reheating schemes. At the same time a consumption of 8·77 lb. per kilowatt-hour is given in col. 3 for 500 lb. pressure, 219 degrees F. superheat, the vacuum being the same as before. This has the effect of showing a very much smaller difference in consumption between the two schemes than we should have expected to find, while the consumption for a set operating on 215 lb. pressure, 250 degrees F. superheat, and a vacuum of 2 inches absolute is shown in Schedule 3, col. 1, as 11·1 lb. per kilowatt-hour delivered to the busbars, which is an extremely good figure and perhaps equals the best results that have been obtained with the highest possible vacuum. On page 70 it is suggested that the total works cost is not likely to be affected by the use of higher pressures and temperatures. Although we think that a sufficiently strong case can be made out for the use of high-pressure and high-temperature steam to warrant its adoption, we can scarcely agree with the above remarks as, so far as we can see, very much the same kind of pioneer work will have to be done as was done in going from 120 lb. to 200 lb. to ascertain the most suitable materials to adopt for the pressures. I am quite sure that a much more difficult problem has to be solved before we can go to temperatures exceeding 650 degrees F., and to go 50 degrees above this temperature appears to introduce a fresh set of complications. We have not yet been able to discover any cast iron, bronze, or yellow metal, that can stand such temperatures as these. It would therefore appear that big discoveries will have to be made before full advantage can be taken of high-temperature steam. Steel for pipes, superheaters, boilers, and valve bodies does not appear to be such a difficult matter. It is the working faces that appear to offer such a great difficulty. It will be remembered that a few years ago German firms supplied to this country and our Colonies large steam turbines, giving most extraordinary guarantees as to the value of their cast iron at high temperatures. Since then experience has shown that the German guarantee was worth very little and that their cast iron was just as liable to distortion as other cast iron. Pipe and boiler coverings where subjected to these very high temperatures will require a special amount of consideration, as there is little doubt that the limit has been now reached with pipe coverings in their present form; and yet the success of the scheme depends on the efficiency of the insulation value of the pipe covering. The maintenance of auxiliaries is no small item on high-temperature jobs, and unless the greatest possible care is exercised in the selection of proper traps, disaster is almost sure to follow. On page 79 the question of $CO_2$ and oxygen in the feed water is dealt with. I should like to know how it is that there is a greater danger of these gases being dissolved in the water when working on the high pressures, as I am at a loss to see how an increase in quantity is possible. I fully appreciate the necessity of keeping these gases down to a minimum; the higher the pressure at which the boiler is worked the greater is the care required. On page 80 the question of jointing material for use on the cylinder faces and pipe joints is dealt with, and it is suggested that corrugated rings and fibrine jointing compound are the most suitable. So far as our experience goes, the thinner the material that is put into a joint for packing purposes, the better chance there is of the joint withstanding the working conditions. Steel bolts are advocated and not wrought iron. We have experienced great difficulty at certain positions on turbine cylinders with steel bolts, and we find that where they have been used with steel nuts on high-temperature jobs, the nuts have very frequently to be cut off, having seized on to the thread; whilst in other positions where studs have to be used we have had to adopt iron owing to the fact that steel crystallized so rapidly that it would not stand the normal working strain, whereas we have not known an iron bolt or stud to fail under working conditions when the material is of reasonable quality. I am glad to note the author's remark on page 81, that valve manufacturers have already made valves for a working pressure of 400 lb., and that they are prepared for pressures up to 600 lb. and a temperature of 700° F.

**Mr. R. Dowson:** The author puts forward two possible means of escape from the present unfortunate necessity of having to throw away large quantities of heat via the condenser. One of them is the suggestion to use some substance, other than water, possessing a smaller latent heat of vaporization; the other is the possibility of making a commercial success of the gas turbine. These two suggestions do not seem to me to offer such an unqualified solution of our difficulties as would appear at first sight. Using a similar temperature-entropy diagram to those in the paper, it is clear that, if we are confined to moderate temperatures and to the use of a liquid as our heat conveyor

* Paper by Mr. J. H. Shaw (see page 73).

the efficiency of the cycle is given by the ratio of the area A B C P A to the area A B C Q H A in Fig. A herewith. Now, from this diagram it is evident that we can increase this ratio in two ways :—(1) By making the steam-line C E E′ further away to the right ; the area A B C P A then approximates more closely to a rectangle, instead of to a triangle. (2) By making the water line A B steeper, which has the same effect. Now condition (1) clearly means the use of a liquid with a latent heat larger than that of water, instead of a smaller ; whilst condition (2) necessitates the use of a liquid possessing a smaller specific heat than that of water. In other words, if L be the latent heat of vaporization per lb. of liquid, and $\sigma$ is its specific heat, we require the ratio $L/\sigma$ to be a maximum. I do not know of any substance which pre-eminently possesses

vaporize liquid sulphur dioxide for use in another cylinder. The exhaust sulphur dioxide was then condensed by the usual condensing plant. The development of the exhaust steam turbine, however, which could take advantage of a much higher vacuum than the piston engine, soon caused the binary-vapour principle to be abandoned, as the only advantage of the latter is that at the lowest working temperature the vapour pressure of the sulphur dioxide is still considerable, and consequently no high vacuum is involved.

With regard to the second proposed solution—the gas turbine—let us suppose that we have so far progressed as regards materials for construction that a working temperature of 1,000° F. is possible, and let us compare a gas-turbine cycle with a steam-turbine cycle. Suppose the steam-turbine cycle is represented in

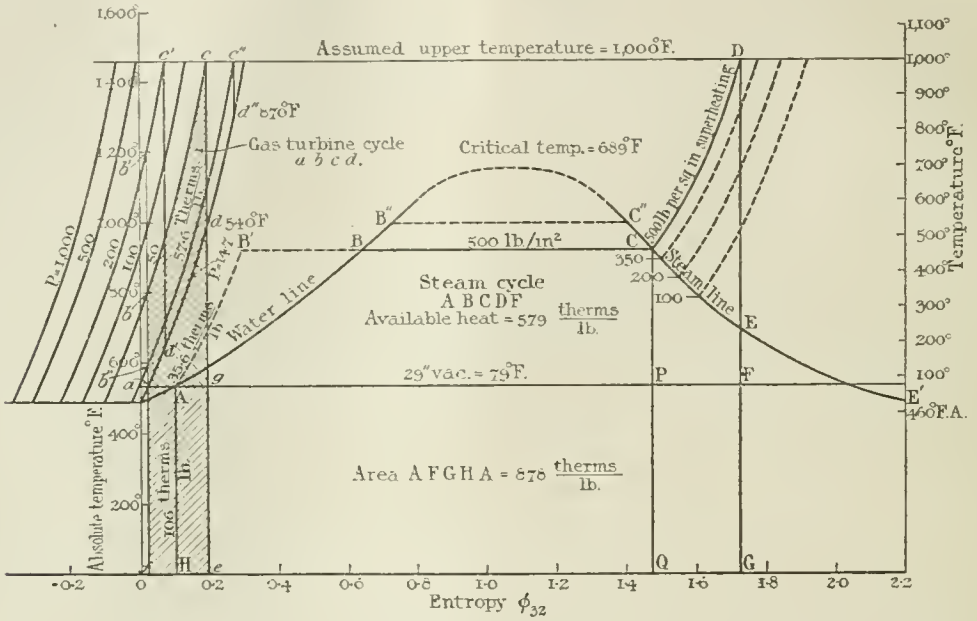



Fig. A.—Temperature-Entropy diagram for steam and gas-turbine cycles.

this characteristic. Water has a high latent heat, but a high specific heat also. Whilst many chemical compounds possessing a high vapour pressure, such as sulphur dioxide, ammonia, carbon dioxide, etc., occur to the mind as possible substitutes, they are none of them so suitable as water. Either the latent heat is very low, or the specific heat of the liquid is high, or the vapour pressure is too high to be manageable. It is not at all clear, then, how we can improve on water as our heat conveyor. As pointed out by Mr. H. M. Martin, the molecular structure of the vapour used also complicates the problem.* As an undergraduate, I remember attending a lecture on the subject of the "binary-vapour" engine, which was, it appears, actually tried about the year 1903. In this plant, steam at the usual boiler pressure was expanded in an ordinary engine cylinder, the exhaust steam being utilized to

* *Engineering*, vol. 103, p. 35.

Fig. A by the area A B C D F, the steam conditions being 500 lb. stop-valve pressure, 1,000° F. stop-valve temperature, exhaust vacuum 29 inches. Then

$$\frac{\text{A B C D F}}{\text{A B C D G H}}$$

is the efficiency. For a gas-turbine cycle working at 1,000° F., and with atmospheric exhaust pressure, the diagram presents some difficulty. If we compress adiabatically along a $b'$, very little heat is taken in per lb. along $b'\,c'$, and the engine is practically a hot-air turbine, in which the air is heated by a jet of gas burning in it. The work done per lb. of mixture is very small, although the diagram efficiency is fairly high. On the other hand, if we use very small compression along $a\ b''$ and a considerable amount of heating along $b''\,c''$, the diagram of work is again very small, and inefficient also, for the exhaust takes place at a high temperature (870° F.). If, then, we compromise, and take a diagram such as $a\ b\ c\ d$, we

can make the following comparison between the steam-turbine cycle and the gas-turbine cycle :—

| *Gas-turbine Cycle at* 1,000° F. | *Steam-turbine Cycle at* 1,000° F. |
|---|---|
| 1. Small quantity of heat taken in per lb. of gases, and low initial pressure. This implies large weight of working fluid for a given output; large blade-heights; and low speeds of rotation. | 1. Large quantity of heat taken in per lb. of steam, and high initial pressure. This implies smaller weight of working fluid for a given output; small initial blade-heights, and high speeds of rotation. |
| 2. Diagram efficiency 29 per cent. | 2. Diagram efficiency 39·9 per cent × boiler efficiency 75 per cent = 29·8 per cent. |
| 3. Exhaust at 540° F. with consequent loss of the triangular area *a d g*. | 3. Exhaust at 79° F. with no loss of diagram area. This, however, implies large blade passages at the exhaust end. |
| 4. Air compressor required for compression, to deal with large volumes of air at atmospheric pressure. | 4. No compressor required beyond the ordinary feed-pump. |
| 5. No cooler required at exhaust, the gases being simply thrown away, and a fresh supply taken in. | 5. Cooler required (condenser). |

This comparison appears to me to be in favour of the steam cycle, since items (3) and (4) are serious objections to the gas turbine, for the exhaust throws away heat at a higher temperature than necessary. Some of this heat might be recovered by raising steam with it, but this would necessitate additional plant with its attendant losses. The real difficulty will be the air compressor, as it will require to be large and efficient This is, I think, the point where most gas-turbine projects break down, as the power absorbed by the compressor may be more than the output of the turbine. There is another point to be noticed in comparing the two cycles. There seems to be an idea that one of the reasons why the steam cycle is necessarily inefficient is that large quantities of latent heat have to be thrown away at exhaust. Let us make a heat balance (see Table below) for each cycle, taking the efficiency ratio as 100 per cent in each case, and see if this is really true. With 75 per cent boiler plant efficiency, 45 per cent of the heat required to raise each lb. of steam is thrown away at the exhaust; and with the gas-turbine cycle, the percentage of heat per lb. of gases thrown away at the exhaust is 71. Comparing the two columns for the steam-turbine plant, it seems to me that we ought rather to concentrate on the suppression of boiler-plant losses, so as to start off with a really high thermal efficiency. Finally, it appears to me that in order to make a gas turbine which will put the steam turbine out of court, we must be able to realize a very much higher working temperature than 1,000° F., and also find some means of efficiently compressing the incoming air. These two problems present very grave difficulties at the present time, and one can see little hope of their solution in the future.

Coming back again to the problem of improving existing types of plant, I am generally in agreement with the author where he claims that it will be necessary to increase both the initial pressure and the temperature of the steam, at any rate so far as the turbine is concerned. It appears to me that if we raise the steam pressure only, it would be likely, if anything, to impair the economy instead of improving it. For referring to Fig. A again, we see that heat is taken into the working fluid along the irregularly sloping line A B C D. Now we know from our theory of heat engines, that for maximum efficiency all the heat must be taken in at the highest temperature. If, by any means, for given "upper" and "lower" temperatures we can raise the mean temperature at which heat is taken in, we might expect to approach nearer to the ideal. The only way this can be done, however, is by raising the line B C to a position B″ C″,

Heat Balance for Steam and Gas Turbine Cycles at 1,000° F.

| | Steam Turbine Plant (500 lb. stop-valve pressure) | | | | Gas Turbine (internal combustion) | |
|---|---|---|---|---|---|---|
| | 0·75 Boiler Plant Efficiency | | 0·85 Boiler Plant Efficiency | | 100 % Heat Efficiency | |
| 1. To raise each lb. of steam or gases requires .. .. | 1,940 therms per lb. | | 1,710 therms per lb. | | 199 therms per lb. | |
| 2. Each lb. of steam or gases entering turbine contains.. | 1,457 " | =25·0 % loss | 1,457 " | =15 % loss | 199 " | |
| 3. Per lb. of steam or gases the turbine could utilize .. | 579 " | =29·8 % | 579 " | =33·8 % | 57·6 " | 29·0 % |
| 4. And rejects at exhaust .. .. .. .. .. | 878 " | 45·2 % | 878 " | 51·2 % | 141·6 " | 71·0 % |
| Total .. .. | | 100·0 % | | 100·0 % | | 100·0 % |

say. This means that we must raise the steam pressure, and we then come up against three difficulties. The first is that, in order to raise the mean temperature by a reasonable amount, a very great increase in pressure will be necessary. In fact, we can never attain even the "critical" temperature of 689° F. by this means, for the saturation pressure would then be as high as

2,050 lb per sq. in. Secondly, the density of the steam soon becomes so great that all theoretical gain due to increased mean temperature would be outweighed by internal losses in the early stages of the turbine. Thirdly, the saturation point would be carried further up the blading, with the result that the performance of the exhaust-end stages would suffer to a greater extent than at present. On the other hand, if the temperature at which the steam enters the turbine is raised also, we can then discount to some extent the increased density of the steam due to a reasonable increase in boiler pressure. Also the point at which condensation occurs in the turbine can be staved off. It appears to me, therefore, that a steam temperature of 1,000° F. and a steam pressure of, say, 350 lb. per sq. in. would be likely to produce a distinct economy, could we but do it successfully. Alternatively, suppose that we content ourselves, for the time being, with a steam pressure of, say, 250 lb. per sq. in. and a temperature of 750° F. Then with an efficient turbine the saturation point might be reached when the steam has expanded down to about atmospheric pressure. Now, whatever the cause of poor stage efficiency with saturated steam may be, there can be no doubt about the fact. It appears to me, then, that an economy ought to be obtained if the steam is drawn completely out of the turbine just before the initial superheat is lost, and is "reheated" by means of some waste-heat supply from the boiler plant. If we can superheat the steam again to such a degree that on finally reaching the exhaust this second superheat has not quite disappeared, we should avoid the above-mentioned poor stage efficiency in the exhaust-end blading. I cannot quote any actual test figures as to the economy to be obtained by this procedure, as those of our designs which are intended to utilize the idea have not yet been put into operation, nor do there appear to be any recent published data on the subject. On paper, however, even neglecting the higher stage efficiency always associated with the use of superheated steam as against wet steam, there appears to be a distinct gain in economy. In other words the ratio

$$\left(\frac{\text{useful work at turbine coupling}}{\text{heat in fuel burned}}\right)$$

per lb. of fuel should be distinctly greater than with no "Reheat."

In conclusion, I should like to refer once more to the last section of the paper, in which the author refers to the extra internal losses which are to be expected at the high-pressure end of turbines, when the initial steam pressure is raised. I presume he is referring to the fact that the incoming steam will be denser. It appears to me, as I have already indicated, that the economy (of both types of turbine) would probably suffer to some extent due to this cause. For in the case of impulse turbines the disc losses and in that of reaction turbines the blade-clearance leakages are, in general, proportional to the density of the steam; gland and dummy piston leakages also depend upon the steam pressure. The general trend of past and present design seems to be as follows:—Consider turbines of large output, where the highest economy is needed. All turbine builders are, I think, agreed that reaction blading has an inherently higher efficiency than impulse blading, and this advantage will, I think, be maintained, even when higher steam pressures are adopted. The higher efficiency is apparently due to the fact that it is impossible to deflect a high-velocity steam jet without serious friction, eddies, and shock. Now, the steam-jet velocity in impulse blading has reached its maximum value at the very moment when it is being deflected by the curved surfaces of the moving blades. In reaction blading, however, the change in direction of the steam flow is much less, as the inlet angle is 90° and the maximum jet velocity is not attained until the exit from the curved surfaces is approached. For a given mean blade speed, also, the maximum velocity is only one-half of that in an impulse element, if the same relative point on the two efficiency curves is considered. This being so, it is necessary to incorporate some other desirable feature in the impulse turbine, as an offset. This feature is comparative shortness—an important matter, especially when it is a question of getting a plant into limited floor space. The possibility of partial admission, and the use of high mean blade speeds, have therefore been taken full advantage of to further this object. When, however, it was discovered how very injurious to economy partial admission really is—owing to the fact that blade "ventilation" losses are much more serious than pure disc friction—efforts had to be made to eliminate it as far as possible without adding to the length of the turbine. Some builders achieve this by commencing with a two-row "Curtis," followed by full-admission "Rateau" wheels. The argument appears to be that although the "Curtis" wheel itself involves partial steam admission and comparatively low inherent blade efficiency, yet owing to the fact that it is revolving in comparatively low-density steam it is no worse in economy than the equivalent "Rateau" wheels operating in steam at a higher average density and with greater partial admission. Some American builders meet the difficulty by commencing with a full admission "Rateau" wheel of small diameter, and make each successive wheel larger than the one before. This naturally tends to lengthen the turbine, because more wheels are necessary in order to work at a good overall efficiency. The mean blade-speed of the last wheel is therefore raised to the limit of safety. When, however, higher steam conditions have to be met, the length will have to be increased in order to include sufficient wheels to utilize efficiently the extra available heat in the steam. It appears, then, that in view of critical speeds of rotation, the tandem-cylinder design will be ultimately adopted as in the reaction type, either with or without a double-ended low-pressure cylinder. The advantage of comparative short length in the impulse type will thus be gradually discounted, since the length over the actual blading is only a fraction of the total length. Finally, then, it appears to me that although the overall efficiency-ratio in both types may be discounted to some extent by the use of initially denser steam, there seems to be no doubt that the thermodynamic efficiency, or

in other words the fuel economy, will be improved by a judicious increase of both steam pressure and temperature, and that it is in the direction of higher temperatures that we should strive most.

**Mr. J. H. Shaw** (*in reply*): In reply to Mr. Jackson, I would say that the steam consumptions given in Schedules 2 and 3 are based on a turbine ratio efficiency of 80 per cent, the corrections used being the standard corrections as given in Mr. Baumann's paper. I am aware that turbines are not at present being built to give this high efficiency, but I have no doubt they will be in the near future. When we raise the pressure from 200 lb. to 500 lb. I do not think we shall have to go through the same experience that engineers did when the steam pressure was raised from 120 lb. to 200 lb. Engineers are now very much better educated, and the means of spreading knowledge have so much improved that almost any engineer who has to tackle a part of the problem is well aware of the difficulties, and by a certain selection of materials can avoid the majority of them. All yellow metals must be eliminated, also cast iron. In my early replies to the discussion I dealt with the question of cast iron as put forward by the Germans, and we must be careful in the future not to be taken in by what are only selling points. Unfortunately, like a lot of other German methods, the materials they recommended lasted until the period of the guarantee had expired. I quite agree with Mr. Jackson that there is very little more need to keep down the amounts of air and other gases dissolved in the water with high-pressure plants than with others, except that the temperature of evaporation with high-pressure plants is raised.

I am pleased to see that Mr. Dowson recommends reheating the steam just before saturation is reached, as from inquiries I had made it appeared that the reheating was to be carried out at almost any pressure that suited the individual engineer. The correct time to reheat is before the dew point, and the amount of reheat required is that which will ensure that the superheat has practically disappeared when the condenser tubes are reached.

## Scottish Centre, at Glasgow, 10 December, 1918.

**Mr. W. J. Poole**: I agree with the author that as far as the turbine itself is concerned there is no reason to expect difficulties. In fact the makers have anticipated the developments now under discussion. Mr. Baumann, for instance, has designed a system of nozzle blocks which are in effect flexibly connected to the turbine casing; they are connected rigidly at one point only but are otherwise free to move, of course within predetermined limits. This removes all expansion strains from the casing and also allows the latter to be made symmetrical. At the same time the nozzle blocks can be removed independently of each other with the minimum amount of trouble and without dismantling anything else. With this arrangement of nozzles, a perfectly symmetrical cast-steel casing, and what is practically a three-point support, there should be no anxiety regarding the ability of the turbine to withstand any temperature and pressure likely to be used in practice. As far as the boilers are concerned, the makers can be relied on to take care of themselves, but when it comes to pipe work and accessories such as stop valves, steam traps, drain valves, and similar apparatus, one sincerely hopes that history will not repeat itself. Twenty years ago during the winter of 1898-99 the Glasgow Corporation Electricity Department increased the steam pressure then in use at their stations from 150 lb. to 210 lb. and at the same time fitted the boilers with superheaters. The new plant had to be installed somewhat hurriedly and the superheaters were larger than the actual requirements then called for, with the result that at peak load the superheat approached a high figure, probably between 600 and 650 degrees F., and though the steam pipes themselves gave no trouble (they were steel with welded flanges) the valves, traps, etc., though the best of their kind then available, gave endless trouble and had to be altered and made suitable by a system of what was really trial and error. Of course a very great deal has been learned during the last 20 years regarding the design of apparatus for use with high temperatures, but the increase proposed is a very big one, and even now can we agree that there is such a thing as a 1-inch valve suitable for, say, high-pressure drains, which will behave satisfactorily for any length of time under a pressure of 450 lb. and a temperature which may vary between 100° and 700° F.? There is just one other point that I should like to draw attention to, as I cannot recollect having seen it mentioned. It concerns not temperatures but pressures. Suppose, for instance, we have a main steam pipe of even a moderate diameter, say 10 inches: the area of this pipe is 78·5 square inches, and at 450 lb. pressure the thrust due to the steam pressure alone would be approximately 15 tons. If the pipe is flexible, as it would be, and anchored at one end, say to a main header, with the other end connected to, say, a superheater stop valve, the thrust on the flanges of this valve from steam pressure alone would vary between zero and 15 tons, according to whether the pipe was in use or not. Again, if the valve were mounted on the top of a stand-pipe, as is very often the case, the leverage on the lower flange of this pipe would be enormous. It would appear, therefore, that the only way out of the difficulty is to provide adjustable tension rods, not across the expansion piece but all the way between the stop valve body and the main header. These tension rods would absorb the thrust and would at the same time allow the expansion bend to fulfil its proper function, while maintaining the valve on the superheater and also the headers at their relatively correct distances apart. I think it is with details like these and not with turbines or boilers that troubles are likely to arise.

**Staff-Sergeant L. M. Jockel, R.E.**: I am afraid I cannot agree with the author on page 73 where he says "There is little doubt that the majority of power

station engineers have given attention to the efficient utilization of steam at the lower ranges of temperature and pressure, and have been during the past few years considering the upper range." There is a very great deal yet to be done to improve the position with regard to the lower limits of temperature and pressure, and it is at this point that I think we may expect some further improvements in the very near future, particularly if we remember that something like 70 per cent of the total heat of the steam is rejected to the condenser. On page 74 in connection with the results of tests of high-pressure or high-temperature steam-generating plant, the author's statement that the boiler and turbine test results should be considered separately seems to require further explanation. I am not quite sure what he means. I agree that when considering separate items of plant for specific purposes his statement may be quite right, but in general operation the tendency is to consider the whole unit of plant (boiler, economizer, turbine, and condenser) from an efficiency point of view. The author's temperature-entropy diagrams on page 74 are helpful, but in turbine problems the Mollier diagram is necessary, and even then one's calculations are often considerably modified in the working of the plant. I have found this to be particularly the case on impulse turbines working under different superheats. The results sometimes exceeded one's expectations in steam consumption, due attention of course being paid to the safe temperature limit. In Schedule I on page 76 the figures given seem quite moderate, but there is rather a lack of detail. Presumably the condenser auxiliaries are steam-turbine driven, and it would have been interesting if the author had thrown more light on his heat balance calculations, taking into consideration all the auxiliary plant allowed for in the Schedule. The load factor is of immense importance, and in this connection 100 per cent and 50 per cent are mentioned. There is nothing below that. I agree that in the future we shall have a 50 per cent load factor, but at present few stations work at anything higher than 30 to 35 per cent, and 50 and 60 per cent seem to be alone obtained by large power companies working on a bulk-supply load only. The author is rather optimistic over this point, unless he is considering a bulk-supply power company's plant. I am glad to see the reference in the Schedule to the ratio of circulating water to steam, because in many power stations the proportion of circulating water to steam is excessive. The figure of 45 as an average is moderate, and could be easily obtained in good practice. I have seen 33 and 34 obtained, and such figures are successfully secured from day to day. The figure is of course very important when cooling towers have unfortunately to be employed, as is the case in most of the large city stations. I am sorry to note that the author is not in favour of high vacua, for there is no doubt that a vacuum of 29 inches (30 inch barometer) will be regularly worked to in the near future with practically all large units of plant. I was interested in his remarks on metallurgical considerations, and I am glad to see that he realizes the importance of these. Before adopting much higher pressures and temperatures we require greater knowledge of the metals employed, particularly in the matter of flanges and bolts. My experience may have been unfortunate, but I have seen a considerable amount of trouble even with 160 lb. pressure and 200 degrees F. superheat in this connection. I think the question of these two items ought to be more stringently dealt with in specifications. The elimination of joints in steam pipes is a problem, and difficulties will undoubtedly be experienced in connection with expansion due to the use of high temperatures. So far as bolts are concerned, I attribute the failure to the large stress put upon them, which is absolutely unfair to any method of fastening, except a bolt of very special design. When one considers that the erection of pipe work is usually done at normal temperatures, and then operated at perhaps 600° F., the difficulties are obvious. In my opinion it would be unwise to jump to very much higher pressures and temperatures, and even for requirements in the near future it would seem that a pressure of 250 to 275 lb. per square inch and a total temperature of 650° F. are quite sound practice. I am hopeful that in the near future we shall be able to test our iron and steel work in situ by electrical or magnetic methods. I believe research work is in progress at present in that direction Incidentally this should be a factor of importance to boiler inspectors and boiler insurance companies, who seem to fight shy of anything above 200 or 250 lb. pressure. I think, however, it would be unwise at present to use higher pressures than, say, 275 lb. per square inch, unless we adopt American practice absolutely and go straight for the super-power station principle which has been proposed in the Coal Conservation Sub-Committee's Report. With regard to turbines, I have not had experience of very large units, but it seems to me that the line of development should be on the two-cylinder basis of the high-pressure and the low-pressure turbine. I consider it to be absolutely necessary to split the turbine into two sections. I have seen some bad failures with mixed-pressure turbines, and it seems to me we could get a cheaper machine by insisting upon the two-cylinder principle. It also allows the low-pressure unit to be used alone in the event of an accident to a large turbine plant, such as the two very bad smashes which recently occurred in America. It is quite possible with the two-cylinder design to get some load out of the turbine under fairly efficient conditions. The high-pressure portion could be specially constructed to suit high pressures and temperatures, and the low-pressure cylinder being of double-flow design would offer marked advantages in regard to blade-leaving area and diminution of end thrust. The condenser water heads could be designed so that the tubes could be cleaned in sections without shutting down the turbine, or the condenser itself in half-duty units, while the condenser auxiliaries would be steam-turbine driven and arranged in half-duty units. Too much attention cannot be focused on the condensing plant of large turbine sets, for it is at the low-temperature end that greater economies can generally be effected.

**Mr. R. B. Mitchell:** The wisest plan seems to me to be to advance by moderate steps in the matter

of pressures and temperatures and not, so to speak, take a leap in the dark. America is generally ahead of this country in electrical matters, and this is certainly the case as regards the size of turbo-alternators recently placed in commission. In this connection it would be interesting to know if the series of failures in America of these very large sets had anything to do with high pressure or superheat. They certainly seem to have had a most unfortunate experience. I believe, however, that in at least two cases the failure originated towards the low-pressure end in the 17th or 18th wheel, and in one of these cases not while on load but during an overspeed test. It would be worth while to inquire into the work which has already been done at Rugby and which is soon to be done at the Tees-side station of the Newcastle Electric Supply Company: this will no doubt provide accurate data upon which further advances can be made. I agree that the use of higher pressures will mean the use of steam pipes of smaller diameter, although in this connection the author's figures on page 81 for a 20,000-kw. set at 200 lb. and 800° F. give the steam pipe as of 15 inches diameter. This seems to be on the small side. The 15,000-kw. sets at Dalmarnock station which will be put into commission next year (1910) will have 16-inch pipes and the pressure is to be 275 lb. at the boiler, with a temperature of 700° F. The author states that the boiler of the future will be of the flash type with no reserve. While admitting that this may be so, it is regrettable that it should be so, as a boiler which holds a good body of water is a great asset in a station where sudden peak loads have to be dealt with. I agree that the old method of arranging for ring mains on steam-pipe systems is bad and would be difficult to maintain with present-day pressures and temperatures, apart altogether from its inefficiency. With piping design on the unit principle, the author states that "a small equalizing main need only be provided at the end of the boiler house." I take it that he means this is for equalizing purposes only. Would it not be well to have this pipe at least equal to the pipe supplying one turbine unit, so that the overload capacity of the boiler could be utilized to the fullest extent and each section of boilers need not necessarily run its own turbine only? The size of the pipe connecting the boiler-house sections in Dalmarnock is 16 inches, although it is not designed quite on the unit principle, but one section of eight boilers feeds into a common receiver from which steam is supplied to two turbine units, and it is these receivers in each section of the boiler house which are connected together by a 16-inch pipe. Steam pipes with welded flanges have given, in our experience, excellent results at the moderate pressures and temperatures now in use, but there seems to be a contrary opinion favouring riveted flanges. With regard to the effect of these high pressures on economizer design, I have not seen it mentioned that economizer makers have put forward a scheme in which the boiler feed-pump does not deal with the water until after it has passed through the economizer. This, of course, leads to complications and it may be preferable to make the economizer an integral part of the boiler, as suggested in the paper, or to use the waste gases to pre-heat the air supply to the furnaces and do away with economizers altogether. Mr. Poole mentioned the old days when the superheaters at Port Dundas were found to be too large. These superheaters were reduced at that time to suit the conditions existing with reciprocating engines, but now we should be very glad to have them back at the old size.

**Mr. D. M. Macleod**: I think the author has made out a good case for both higher pressures and higher temperatures, and I have no doubt that what he has put on record will form an accurate forecast of the probable line of development in the near future. I am inclined, however, to share the view of the other speakers who have expressed the opinion that it would be unwise to act precipitately. One recalls the somewhat startling trouble which lay in wait for mains superintendents in the closing years of last century, when the working voltage was doubled. It was then found that copper strip mains, whilst very satisfactory at a working pressure of about 115 and 230 volts, were altogether unsuitable for the increased pressure. This serves as an indication of what one may expect when one goes in for new conditions for which no reliable data are available. It is notable that, since the time of James Watt, nearly all the time and care of engineers has been devoted to securing the economies resulting from improved vacuum. The paper bears witness of the great economies to be effected at the other end of the scale, and shows that it is possible, with stations not by any means ideally situated as regards condensing water supplies, to achieve good results by resorting to higher pressures and temperatures. There are two points I should like to mention with regard to the practical application of these higher pressures and temperatures. First, I doubt if expansion bends at these high pressures would yield satisfactory results. I favour the use of expansion joints in preference to bends, and have found these to do well in service. It seems better to determine beforehand the point at which pipe movement shall take place and to make provision for such movement at these points and there alone, rather than to rely upon the somewhat indefinite movement due to the distortion of large and unwieldy pipe bends. In the second place, from the result of observation, I have found that the ordinary design of pipe anchor—consisting of stool and glands—is not at all satisfactory. In actual practice it is found that the pipe is thrust or pulled through such anchors. Latterly, I have adopted an anchor of such a design that the stool forms an integral part of the pipe line. With such a design as this, there can be no question of slipping.

**Mr. A. Page**: I have worked out the overall efficiency (i.e. coal to electrical units on the busbars) for several of the cases given in the Schedules. The highest on 100 per cent load factor is 22·2 per cent. Last year in the area of 25 miles round and including Glasgow, an area containing 10 power stations, the efficiency (coal to units sold) was only 8·0 per cent. Comparing this with the figures given on page 79 for a 50 per cent load factor and 200 lb. boiler pressure, in which case the efficiency is 15·1 per cent, it will be admitted that even after due allowance has been made

for variation in the working conditions there is ample scope for improvement in this district. With the starting up of the larger sets on order, some of which are now being erected, this improvement should not be long delayed. The turbo-generators in question, under full-load conditions and assuming a boiler-house efficiency slightly higher than that used by the author, will show an efficiency of 21 per cent. No reference is made in the paper to bleeding the turbine at the low-pressure stages for the purpose of heating the feed water. This is a decided advantage and appreciably increases the overall efficiency. All the Schedules are extremely interesting and will well repay careful study. It seems to me that the author puts the internal efficiency of the turbine rather high, and the steam consumptions are certainly better than the figures quoted by manufacturers. The assumption of constant boiler-house efficiency in making the calculations is hardly justified, and this is confirmed by what the author says on page 77. Schedule 2 is perhaps the most interesting. The temperature of the steam at the stop valve being the same in each of the three columns, the overall efficiency is respectively 20·5, 20·1, and 22·2 per cent. Incidentally a comparison of the amount of circulating water given in Schedules 1 and 2 shows what an enormous increase is required between vacuums of 28·5 and 29·1 inches. Schedule 3 shows the cooling-tower installation in far too favourable a light; it would require a great deal of demonstration to convince engineers in the West of Scotland that a 28-inch vacuum could be maintained using cooling towers on a large scale. The prevailing weather conditions here, apart from other difficulties, do not allow of it. The author has made out a very good case, as regards working expenses, for the increase of pressure and temperature. The first cost of all the highly specialized apparatus is, however, another question, and with the average load factors prevailing it is very doubtful if the investment would be a paying one.

**Mr. A. E. McColl**: The paper is robbed of half its value in that the capital costs of the various schemes are not given. Although the present market price of turbine plant is in a condition of flux, the comparative cost of the plants for the various pressures would not have been affected. In view of the statement on page 75 that "There is no doubt that the increased density of the steam at the higher pressure will increase the internal losses in the turbine", the figures for the internal efficiency of the turbine (Schedule 1) at 215 lb. and 300 degrees superheat, and 365 lb. and 300 degrees superheat, appear inconsistent. The boiler-room efficiency of 77·5 per cent assumed by the author is on the low side, as sustained efficiencies of 81 and 82 per cent are possible in the largest power houses with modern equipment. The overall efficiency of the author's scheme (500 lb. pressure with 50 per cent load factor consuming per kilowatt-hour 2 lb. of coal of 10,000 therms heat value) works out at 17·1 per cent. Power houses are in operation at present employing steam pressures much lower than the above figure, and with a lower boiler-room efficiency than that assumed by the author, and obtaining overall heat efficiencies slightly higher than the figures given above. It is interesting to compare the results of the Connors Creek power house for sustained operation over a period of 12 months. An efficiency of 17·33 per cent was obtained with a load factor of 41 per cent, a boiler-room efficiency of 76 per cent, and a steam pressure of about 300 lb. The company hope ultimately by the installation of economizers and the employment of higher rotative speeds to reduce the heat expenditure per kilowatt-hour to 17,000 therms, or an overall efficiency of 20 per cent. While it is not at all clear that a good case can be made out for a jump to the maximum pressures the author has advocated, there is no doubt that an increase on present practice is justified. In many cases with stations having ample cooling-water facilities the best results are not aimed at, although the increased cost of fuel justifies the increased expenditure thereon. Engineers generally are content with a good vacuum instead of the best. As the author has pointed out, condenser makers generally design on liberal lines; consequently, condensers are giving in many cases better vacua than the turbines can properly deal with. Part of the increased expenditure which the author advocates on the higher steam pressures might profitably be employed in obtaining lower absolute pressures where the facilities are available, and a better overall heat efficiency be obtained. This does not apply to stations having cooling towers, and there may be justification here for the employment of the highest pressures.

**Mr. C. H. Wright**: I am reminded of a small point in reference to the effects of high pressures and temperatures on materials. In connection with some work on small boilers on which I was engaged a few years ago and which operated at from 350 to 500 lb. per square inch, the gauge glasses were in many cases rapidly wasted or dissolved away. These glasses were of the reflex pattern made of the toughened glass usually employed for this purpose.

**Mr. A. P. Robertson**: It seems to me that if we go to very high pressures and temperatures we must have a very high grade of material for the manufacture of valves, etc. Also the blading on the first stage of turbines will require to stand a very high temperature, but I do not think that should be beyond metallurgists. At present engineers have had trouble with valve chests giving way under high superheat, but that was got over by using cast steel instead of cast iron. I was interested to learn that Mr. Macleod has tried sliding expansion joints and has found them successful. I have always been inclined to try them but was told that they were absolutely no good, that the packing blew out and the joints stuck, and all sorts of troubles were predicted. If one end is anchored and a suitable packing is used the joint ought to move back or forward. I have noticed with steel expansion bends that they lose their elasticity in a short time and are then no better than a rigid pipe, with the result that joints give out and all sorts of troubles arise.

**Mr. R. J. Butler** (*communicated*): The case for higher temperatures and pressures has been set forth in a particularly impartial and unbiased manner, but one feels that the author is not very sanguine as to

the unqualified success of his proposals to go to the extreme limits stated. The following remarks are put forward as being based on experience of ship work, and may be interesting as having some bearing on land-station practice. The conditions obtaining in marine work are much more onerous in view of inaccessibility, lack of solid foundations, and small staff, but these are to some extent balanced by the fact that continuity of operation, although of course of first importance, is not so vital as in power stations. The most general type of boiler now in use in power stations is the Babcock & Wilcox, and in marine work the Babcock and the Yarrow. Some years ago the Admiralty raised the pressure in the boilers fitted on large ships to 300 lb. in the case of the Belleville type, but this rise did not have a very long life, it being found that the water loss (or what is equivalent, the coal wastage) was very high, not only from leaky glands and steam-pipe joints, but also from vapour in an imperceptible form issuing from the hand-hole doors. These doors have their counterpart in the Babcock type and it would be most interesting if the author could state what is the make-up feed—to replace water loss—necessary in the high temperature and pressure plant at Rugby. The Admiralty now fit boilers of 235 lb. working pressure in all vessels except destroyers —in which are invariably fitted boilers of the three-drum type working at 250 lb. per square inch and these of course have three manhole and no hand-hole doors. Besides this water loss, trouble arose in maintaining valve and rod packings tight, and this with saturated steam; and it is the difficulties which accrue from the non-metallic parts, rather than from the metallic parts, which have tended to keep the temperatures and pressures within the present moderate limits. Of these materials packing, lubricants, carbon rings, and lagging are the chief. In some recent ships fitted with high-speed turbines the carbon rings of the glands, although only subject to a pressure of 110 lb. saturated steam, have given a good deal of trouble and necessitated frequent replacements. There are of course machines on the market in which steam-tightening is effected differently, e.g. the labyrinth and water seal of the Westinghouse and the special labyrinth of the Ljungström types, yet there are several which do employ carbon rings, and it is thought that the increased temperature and loading could not be safely applied until more knowledge has been acquired of the successful manufacture of the rings to withstand the new arduous conditions. Serious steam-pipe radiation losses are likewise to be apprehended, particularly as the boiler plant in power stations is usually considerably removed from the engines. With regard to lubricants, this difficulty has been largely overcome, so far as temperatures at present in vogue are concerned, and it is of course only now applicable to auxiliary machines which are yet driven by reciprocating engines, at any rate so far as small stations are concerned. Of the metallic parts involved, much advance has been made in the metallurgy of steel, iron, and the non-ferrous metals, but it must be borne in mind that the strength of most metals diminishes fairly rapidly with increase in temperature, so that the scantlings of the parts become greater more rapidly than would be the case were an increase of pressure solely to be legislated for. This involves an augmented initial cost, thereby minimizing the financial gain obtained by the improved economy due to the employment of the higher ranges suggested. The points raised by some speakers in the discussion as to the difficulty of obtaining small valves and fittings to withstand the temperatures in question can be confirmed, as I know of a recent case where a first-class set of mountings designed for a working pressure of 220 lb. and 250 degrees F. superheat developed serious leaks in the first few months of operation in spite of great care and attention being given to their upkeep. A minor difficulty appears to be the provision of gauge glasses to withstand the temperatures in question, and information on this point will be extremely welcome. On the whole, partly from the reasons stated above and partly perhaps from his innate conservatism, the marine engineer would look askance at the proposals, and in view of the bitter experience already acquired of high maintenance charges with high pressures, his power-station confrère will be well advised to go carefully before making such a large advance.

**Mr. J. W. L. Jones** (*communicated*): It is satisfactory to note on page 79 of the paper that Messrs. Babcock & Wilcox are prepared to supply boilers for 475 lb. per square inch working pressure—it is to be hoped for the sake of healthy competition that there are other water-tube boiler makers who are prepared to do likewise. I agree with Mr. Mitchell and Mr. Page that it would have been interesting if the author had given his views and experience on the system of bleeding the turbine and heating up the feed water with the steam. Turbine manufacturers advocate it on the grounds of efficiency and saving of material in the turbine. It is obvious, therefore, with the feed water heated to a temperature of 250–300° F. that a water economizer is superfluous, and that the adoption of air heaters to utilize the water gases is essential. Preheated air enriches the fuel to the extent of the heat imparted to the air, and for low-grade coals such as it is now the practice to burn it has moreover the effect of bringing about quicker ignition and better combustion. In order to obtain the maximum temperature in the air it should be divided into thin sheets and the flow of the gases should be in the opposite direction to that of the air.

**Mr. W. W. Lackie** (*communicated*): This paper is timely and practical. I think there can be no doubt that if there are two sets of conditions which ultimately give the same steam temperature, the better one is that having the higher pressure and a moderate amount of superheat. In the new Glasgow power station at Dalmarnock the boiler-house pressure is to be 275 lb., and 250 lb. at the stop valve of the turbine. The final temperature of the steam will be about 700° F. I was somewhat astonished to find that the Willans law is applicable to the coal consumption and kilowatt-hours generated per day. I must congratulate Bradford on the excellent results they have had, showing a figure of 2·3 lb. per unit generated plus stand-by coal. The Schedules in the

paper are extremely interesting and must have involved an enormous amount of work. Schedule 5 is very interesting, but I should like to point out that if the additional capital given in the fifth line is spent, there is no saving over the adoption of 215 lb. and 100 degrees F. superheat. I also think that to take the life of the plant as 15 years is on the high side and it would be better to assume it to be 10 years. We must keep in view that the necessary capital expenditure involved in the purchase of a 20,000-kw. set is between £100,000 and £120,000, and it is quite conceivable that such a set if built to stand 365 lb. pressure and 200 degrees F. superheat might cost £20,000 to £30,000 more. It is agreed that we can now find metal to stand a pressure of 500 lb. per square inch, but the question of higher temperature is one that has still to be investigated. A very strong case is at present being made out for doing without the usual feed-water economizers and for withdrawing steam from the turbine at suitable stages and so raising the feed water to 200° F. or more, the flue gases being used for heating air.

**Mr. J. H. Shaw** (*in reply*): Mr. Poole's questions regarding the small steam fittings are quite opportune. Great care must be exercised in the purchase of such fittings, and in order that engineers can ensure that only the proper materials are used it will be necessary in the future for them to purchase the various parts comprising the steam main, such as pipes, valves, fittings, etc., direct from the maker, instead of making a contract for a complete steam range as in the past, in which case the materials used for the manufacture of the valves, etc., can be examined with some certainty of avoiding trouble in the near future. I can assure him that 1-inch steam valves can be purchased now made entirely of ferrous metals, which can be relied on up to 500 lb. pressure and a total temperature of 700° F. I quite agree with Mr. Poole regarding the thrust in steam pipes, which should have greater consideration than is usually given this subject.

In reply to Staff-Sergeant Jockel, I would advise him that the condenser auxiliaries for Schedule 1 are all taken to be electrically driven. With regard to the question of the boiler and turbine test-results being considered separately, it must be remembered that part of an engineer's training is to be able quickly to analyse figures and arrive at the result, which can be memorized and also put down on paper; and if this be the case it is quite useless to compare the results obtained from a modern-equipped extra-high-pressure station against those obtained from a station, which is perhaps 20 years old, working at a lower pressure.

I regret I cannot agree with Mr. Mitchell that the wisest plan is to increase the pressure by moderate steps. It appears to me that if a station or section of a large station is once designed for a certain pressure that station must remain at that pressure or suffer disadvantages due to the use of mixed pressures. For instance, it may be quite possible to run the extra-high-pressure boilers on a lower pressure turbine by diminishing the pressure or passing the steam through a reducing valve, but if the low-pressure boilers are to be used on an extra-high-pressure turbine the machine will not carry its load and will be considerably less efficient if governed by nozzle control. Mr. Mitchell's example of a 16-inch pipe on a 20,000-kw. turbine is not uncommon, and I am of opinion that this practice has grown through the custom of using a certain valve with a small throat area. This valve is often used in quite unsuitable positions, and I fail to see the necessity for its use at all. A much higher steam speed can be used than is at present the practice, if the steam piping is consistently designed and full-way valves employed. This greatly simplifies the piping and also the draining problem.

Mr. Macleod's suggestion of using expansion joints instead of bends cannot have been put forward in a serious manner. It is quite possible that with higher pressures and temperatures a form of metallic packing will have to be used for valve spindles, and that one of the difficulties to be overcome will be that of packing. If this be so, any engineer will be doubtful of introducing into the main steam range a piece of apparatus that requires packing around the outside of the steam pipe. Further, if the expansion joints are not placed in carefully selected positions between fixed anchors they will blow open to their full length when first subjected to pressure, and will never close up again.

Mr. Page's statement giving the efficiency of the power stations around Glasgow is most interesting, and to the progressive engineer most disheartening. I cannot, however, agree with him that 28 inches of vacuum cannot be maintained in a station with cooling towers. In Bradford, where cooling towers are employed and a careful check is kept to ascertain that capital is not wastefully employed to obtain comparatively low costs, the average vacuum is better than 28 inches.

I am pleased to hear from Mr. McColl that he considers a boiler-house efficiency of 77·5 per cent or even higher can be maintained, as I have been severely criticized for assuming such an efficiency, but I am in doubt of attaining a yearly efficiency of 82 per cent as suggested by Mr. McColl.

# DISCUSSION ON

## "THE SUPPLY OF SINGLE-PHASE POWER FROM THREE-PHASE SYSTEMS."*

North Midland Centre, at Leeds. 10 December, 1918.

**Mr. R. H. Campion :** I am afraid that the machine described by the author will revive one of the famous battles of the past in which a good many of us took part, because in this paper the single-phase furnace is strongly advocated, and one almost wonders whether the rotating balancing converter will be able to withstand, without flashing over, the big loads which are thrown on and off these furnaces. I shall be glad if the author will state whether the desired result could be obtained with static condensers, as they would undoubtedly be preferred by the steel makers. I understood the author to say that such condensers are rather limited as regards current, and I should like to know if there is any limit in that respect. In my opinion a great advantage of electric furnaces is their ability to consume their own scrap. Probably, however, the motor-generator is the safest and surest, although not the most efficient, method of supplying current to these furnaces. I understand that there are some towns where only three-phase furnaces are allowed on the mains, and I should therefore like to hear what are the objections to single-phase furnaces where a machine like that described in the paper is installed.

**Mr. S. Simpson :** When one considers the possibilities in regard to electric furnace work the power requirements are very considerable. Take a furnace such as the one mentioned by the author for which he has built the machine described in the paper. That furnace, as I understand it, would have a capacity of about 1·4 tons per heat. That is quite a small furnace, but it requires about 400 kw., and I believe that a 6-ton Snyder furnace would take something like 1,200 k.v.a., and for a 10-ton furnace something like 2,000 k.v.a. When one considers single-phase powers of these amounts drawn from a three-phase system one can at once estimate what the possibilities of unbalance are likely to be if some corrective measure is not adopted. I think the author has justified the points which he has set out to cover in his design and which he enumerates as the requirements of a balancer on page 122. On looking at the test sheet on page 120 it will be observed that there is a very good balance on all three phases on the three-phase side and, moreover, the efficiency is well maintained at full load. The design sheet on page 124 shows that the calculated efficiency is 90·4 per cent. I find from the figures given on page 126 under full-load conditions that the efficiency came out actually on test (i.e. the test on site) to 90·5 per cent, which I think is a very excellent performance when one considers that it was for the first machine of this type. I notice also that, although the author set out to obtain unity power factor on the three-phase side, he has not got quite that result. I make it to be about 0·90 under full-load conditions. On the single-phase side there is one thing I do not understand, namely, the power factor under full-load conditions. From the figures given, this works out at 0·96. I thought this power factor would be considerably less, say, 0·7, the normal figure. American engineers had some very interesting experiences 9 or 10 years ago when they attempted to give large single-phase supplies from three-phase systems. I think they experienced in that connection their first troubles with regard to the heating of machines giving single-phase supply from three-phase generators, and from that point, I believe, arose all the literature which has since been published and which the author has collected in the Appendixes dealing with the theory of this subject, and the evolution of means to get over this difficulty. He has shown us on the screen the balancer fitted with a starting motor, and I take it that is for running up and synchronizing. I suppose he can adopt the same arrangement as with rotary converters to make these machines self-synchronizing. Considering the case of a 10,000-volt supply, would he, say in the case of a 400-k.v.a. balancer, put in windings for that voltage, or would he prefer to step down to a low voltage on the machine? If the latter, it would be necessary to consider the additional transformer cost for such a machine. I take it that in the case of a 6-ton furnace such as I have mentioned, taking about 1,100 k.v.a., there would be no difficulty in putting in higher voltage windings. Also, would he propose to run several furnaces in parallel off the same balancing transformer? Apparently he would lose the stabilizing advantage which at present he gets by keeping the balancer transformer and its furnace as one unit.

**Mr. A. Imbery :** I think the author must be complimented on the extremely low running costs. As regards single-phase work, I think we have to consider the proposition commercially. When a man is asked to spend on a small installation £2,000 extra for a rotary converter or balancer, he considers the proposition a long time before installing such a machine. Of course, without in any way depreciating the work done, I think that from the point of view of an electrical engineer the scientific method is to obtain the desired result most effectively at the least capital outlay. As regards single-phase furnaces, I think that from the supplier's and consumer's points of view the capital cost will have to be kept down if we are to compete with other methods of steel manufacture.

**Mr. J. W. Townley :** I should like to mention that

* Paper by Professor Miles Walker, D.Sc. (see page 109).

with every three-phase furnace with bottom connections the supply authority has got to allow for unbalanced load. In the case of two furnaces with which I have had experience, the bottom lining is not conductive when starting cold. In the case of the Stobie, a two-phase furnace, the two single-phase transformers are put in series and the arc struck across the upper electrodes and the charge, which puts the three-phase side out of balance It was expected that the load would be balanced on this particular system, but it was found necessary to allow this unbalanced load. It was permitted under severe restrictions, but as time went on we found it was possible to relax these restrictions and run the furnace under the above conditions, the currents in the three phases being in the ratio of about 43, 115, and 157. It was found possible to take loads up to about 1,200 or 1,600 k.v.a. with that ratio of current without upsetting our system. The size of the plant supplying the system when that load was on was 5,000 kw. In the case of the Greaves-Etchells furnaces the same thing applies. These have a bottom electrode. It is necessary to put one of the electrodes right into the charge and to work with a single arc until the bottom lining becomes conductive and enables two arcs to be struck. The author suggested that it was not possible to increase the voltage in three-phase furnaces above 100 volts. With the Stobie furnace we found it was possible and did not give any trouble to run at 115 volts. In the Stobie furnace there are four electrodes, two upper and two lower, connected in the bottom lining. A point that is necessary to remember is the maximum size of furnace that can be dealt with by a particular size of plant. The size of furnace should not be more than 15 per cent of the capacity of the plant running in the station, and that has been found to give very successful results. We have a furnace 25 per cent of the capacity of the running plant, and that has been found to give very bad results indeed.

**Mr. W. M. Selvey :** The author rather limited his point at the beginning of the paper by saying he was only going to deal with the electric furnace. If he feels inclined to say something bearing on the use of single-phase power for railway electrification I should be grateful.

**Mr. W. Lang :** One outstanding feature—at any rate to me—is that the author has taken up a very decided and a very strong position in regard to the single-phase furnace being the proper line of progress. I think he is to be complimented on taking such a very decided stand, because even if, as Mr. Campion says, we have the battle of the phases over again, it will be on a subject which will be of primary importance and interest to all concerned in the electrical industry. I note that the machine referred to at the top of page 110 as having a single-phase generator might be $1\frac{1}{2}$ to 2 per cent lower in efficiency than a three-phase generator of the same characteristics, whereas on the opposite side of the page the author refers to its cost being 30 per cent higher. I should like to know if that 30 per cent refers to the first cost and is irrespective of the $1\frac{1}{2}$ to 2 per cent lower efficiency. Another point of very great interest, at any rate to all suppliers of three-phase power, is the figure of 20 per cent given on page 110 under the heading of "Effect of single-phase load on a three-phase generator." I think it is a very important point to know that so long as we keep within 20 per cent of the total load on a station we can with safety use one phase only for any particular work. It would almost indicate a limitation to the usefulness of the plant which the author has described. Possibly, however, this will have no serious bearing on that point, because the development will be much more than 20 per cent of the load of a station in the future.

**Mr. W. E. Burnand** (*communicated*) : A discussion on a paper of this character at the present time tends to become a discussion on electric furnaces, but personally I doubt if this will be the chief use of single-phase power. The disadvantage of short-circuits through the roof lining of a polyphase furnace may be overcome by the use of a liner round the electrode poles of material that does not become conducting at the temperature of the furnace. I am also inclined to think that carbon or graphite is by no means the last word in electrodes for this work, though they have no competitor at the present time. In view of the cost, loss of efficiency, and complication of all known systems of converting two or three-phase to single-phase, I do not think the single-phase furnace can hold its own against the polyphase furnace for any but a small proportion of this work where this conversion is needed ; but in view of the demonstration that as much as 20 per cent of the generator output can be taken single-phase without serious disturbance, it would appear that quite a lot of single-phase work is possible without this conversion. Regarding the actual conversion of three-phase to single-phase, this is analogous to converting power supplied through a pulley to reciprocating power, say by means of a crank and a connecting rod, and as the power supplied to the pulley is continuous, whilst the power taken out of the connecting rod is pulsating, this involves some storage of energy. This is effected by the pulley acting as a flywheel and by the inertia of other parts of the moving system. Electrically, this involves chokers, condensers, or moving machinery and perhaps electro-chemical action (as in the so-called electrolytic condenser) as the possible means of effecting a change of phase where the power supplied is out of phase with the load. Of these methods, the most practicable at present is moving machinery. In addition to rotating machinery, an oscillating or vibrating machine might be utilized, but this looks less promising than the rotary machine for large sizes. The great advantage of the special rotary machine described in the paper is that this combines in one machine a voltage and phase transformer, together with a means of taking current at unity power factor or even leading current from the supply whilst having a high inductance in the secondary. This is a very valuable combination for electric furnace or similar work, but of course the last feature, which involves considerable cost for the leakage path in the stator, and extra copper to carry the low power factor current in the secondary, would also be a disadvantage for most other purposes. Not the least valuable feature of the paper is the demon-

stration that as much as 20 per cent of full load can be taken out of a three-phase generator as single-phase power with an inconsiderable voltage disturbance. On a public supply system this proportion would be considerably reduced owing to the voltage disturbance in the mains being additional to that in the generator. Even if the permissible single-phase power is merely reduced to one-half or one-third of 20 per cent, this is quite a big amount on the large systems of to-day and the larger systems of to-morrow, so that it seems to me that most single-phase loads will simply be taken direct off two wires of the three-phase system, though some extra charge might reasonably be made by the supply authority, over the charge for a normally balanced three-phase supply. I think also that the question of low power factor should be dealt with by the supply people on the basis of cost, rather than by regulations refusing loads below a certain specified power factor. The supply people can supply current at unity power factor at a certain cost. They can also supply wattless current at an average cost of about one-third the cost of unity-power-factor current. There is no difficulty in constructing a meter that will take this into account in sufficiently correct proportion—far nearer to being correct than is possible by a sliding scale based on average power factor—or by the usual watt-hour meter, which is absolutely a false standard for most industrial loads. With a proper metering system which gives the supply people an equal profit on wattless current (which is still "electric supply") as on unity power factor current, the question of power factor is put on a fair basis, and it is open to the consumer to take current at any power factor desired. Whilst at present the watt-hour is the legal standard, undoubtedly this could be supplemented by a further standard taking into account wattless current on a fair basis, since this is a valuable commodity to the consumer and costly to the supplier, and to supply it for nothing (or nominally nothing, which involves an unfair distribution of costs) is about as sensible as giving away a pound of sugar with a pound of fruit to an indefinite proportion of customers.

**Professor Miles Walker** (*in reply*): As Mr. Campion has said, there is no real limit to the current we can put into a condenser if we can get sufficient capacity. The Mansbridge condenser, which is now manufactured in considerable quantities, gets a large capacity into small compass, and there is no doubt that it is quite a commercial apparatus. Of course, one is always a little afraid with condensers: the voltage is across a small thickness of dielectric and there always appears to be an element of danger even when several condensers are connected in series. In the future we may have condensers sufficiently cheap to work them at a very low voltage gradient and get quite good results.

What Mr. Simpson said with regard to the power required by furnaces in the future is very important. It is quite possible that we may have furnaces of a capacity of thousands of kilowatts, not only for steel making, but very possibly for iron smelting; and while at present prices it is not altogether a commercial proposition, yet there are so many advantages to be gained that the matter is being very seriously considered by a number of people, although it may be some years before electric power becomes sufficiently cheap in this country to make it worth while. Of course for steel melting during the war electric furnaces have been widely used and have formed quite an important function in the utilization of scrap material.

The efficiency that Mr. Simpson referred to is perhaps giving me credit which I ought not to have. If he looks at the calculation sheet in the paper he will see some uncertain quantities—losses on load. The electrical engineer knows nothing about these losses on load. Besides the iron loss, the copper loss, friction and windage, etc., which are capable of measurement, there are additional losses. Manufacturers make a guess at these losses, and it is only a matter of making a big enough guess for the efficiency to appear lower than the efficiency obtained. It is merely an estimated figure and might just as likely come too high as too low. The losses in the end plates, losses in the dampers, and so on, are a big proportion. The iron loss is 12 kw. I have allowed 8 kw. for what may be called extraneous losses.

With regard to the other figures in the test, the power factor in this case was not unity. In the first place, the load was not quite balanced, and the power factor with unbalanced load cannot easily be stated. With regard to the power factor on the low-tension side, if it be measured at the terminals of the machine it is quite high, perhaps 0·96. Nevertheless the internal power factor is only 0·7. The current lags 45 degrees behind the rotating flux from the field magnet which generates what may be called the applied E.M.F. The leakage flux combines with the flux from the pole and the two together generate an E.M.F. sufficient to overcome the resistance of the circuit and the same reactance in the furnace. We have a generator pressure of 220 volts due to the flux which on no load embraces the whole of the single-phase conductors. When we put load on the machine the whole of the flux does not embrace the single-phase conductors. The machine can be made self-synchronizing, if required, just as a synchronous motor can be made self-synchronizing. As Mr. Simpson says, the question of an 11,000-volt machine would depend on the size of the machine. If we had a machine of fair size we could build it to take 11,000 volts. It is possible to make a thoroughly reliable winding for a large machine. If it is a small machine a transformer would probably have to be installed.

The actual weight of copper and iron in the machine is little more than the copper and iron in the transformer. The machine is, however, more expensive because electrical manufacturers charge more for running machinery than for transformers. More labour is required and the prices are much higher. Actually, as the machine is self-ventilating and it can be made to run at a high speed, the amounts of copper and iron are not higher than in the transformer. Theoretically, one ought to be able to make such a machine without the cost being out of proportion to the cost of a transformer. On the other hand, while some of these prices look very big from an electrical engineer's point of view, it is satisfactory to notice how lightly others

regard them. An electric furnace can make so much money in the year that it pays off the capital cost in a very short time. If we take, say, a 3-ton furnace and get from it about 100 tons a week, and if we get high prices for high-quality steel it is a money-making proposition. The mere cost of plant, even though several thousands of pounds, is a small amount of money from the point of view of the man making the steel. The convenience and use of the plant and, above everything, the cost of running a furnace are more important. Anyone who has seen a furnace after the roof has fallen in will give his full sympathy to the man who has to use it. If the temperature gets too high it makes a great mess. The cost of the lining is great. If the user of the plant can be assured that the cost of re-lining is going to be reduced, he will pay a great deal of money for that assurance.

It is quite possible to connect the furnaces in parallel. The windings are in parallel. This machine has eight separate coils in parallel. These are all brought out, and are connected to one busbar. We need not do that if we have a machine of 2,000 kw. capacity. We can take one or two coils and connect a furnace to them. Each set acts as a generator by itself. It has the same characteristics as the other machine—that is to say, on no load it gives 220 volts and on full load it drops in voltage by the same amount as the whole machine. With full load one can divide the load. We could build a large number of furnaces and get a large area of slag at the right temperature without danger of short-circuits between the carbons.

Mr. Brown said that this method might be used for electric welding. I have not considered that. I do not know enough about the characteristics required for welding.

I have been asked whether it would be an advantage to have our own power station. If we need a big supply, and many electric furnaces, then undoubtedly it would be an advantage, provided we have a good source of power, and cold water, etc., to have our own power station, although I dare say some of the power suppliers would then be pleased to cut prices.

I was interested by the remarks of Mr. Townley about the Stobie furnace and the Greaves-Etchells furnace. It is interesting to hear he is of opinion that with these furnaces it is only satisfactory to have about 15 per cent of the size of the total generating plant. That shows how, when there is no stabilizing influence on the furnace, disturbance on the outside circuit is apt to be caused. Many power engineers will not allow us to connect a single-phase furnace to their networks; they are afraid of short-circuits, and so even a load of 10 or 15 per cent could not be placed on their lines without a transformer. If the balancer is installed we can put on a load equal to the whole of the load supplied. The balancer results in an ordinary three-phase load of unity power factor. In Leven there is one of these balancers running in a comparatively small station. There is a 200-kw. balancer, representing quite a big fraction of the load. Not only that, there is a long line which feeds a number of mills on the way. The load does not cause any more disturbances to this line than the ordinary load of 200 kw. and, even if the furnace happens to be short-circuited, the current falls.

Balancers of this kind could be used for the supply to electric railways, but electric railway supply is always on such a large scale that no doubt it would always be dealt with by single-phase or three-phase generators of special design. I myself do not anticipate, therefore, that there will be any great demand for these balancers for electric railway work.

## Scottish Centre, at Edinburgh, 14 January, 1919.

**Mr. R. B. Mitchell**: On page 110, col. 1, the author states that if the single-phase load does not exceed 20 per cent of the normal three-phase load the voltage disturbance will be inconsiderable. If this were done regularly up to the full 20 per cent, would there not be considerable heating in the generator due to the pulsating flux? I was interested to note that at Bradford 400-kw. single-phase furnaces are thrown on and off the three-phase mains without causing a noticeable unbalancing of the voltage. In Glasgow we have also attempted something on the same lines with success, but on a very much smaller scale; the single-phase supply was required for welding, and the welding transformer was of only 50 kw. capacity. In another case the same thing was done, but in an even smaller way, for glass annealing. With regard to the single-phase furnace with one carbon at the top, what will happen when a number of carbons have to be used owing to an increase in the size of the furnace? Will it be possible to run arcs in parallel satisfactorily? Does not the resistance of each path vary so continually that the arcs are never all in operation together? As regards energy consumption, will the author please state to what extent the single-phase furnace is more efficient than the multiphase one? It seems to me that as systems grow larger the objections put forward against the three-phase furnace will not weigh so heavily. Also, as furnaces are growing rapidly larger and are requiring more and more energy to be dissipated in the furnace, the provision of a rotating balancer will be a very costly item. Is it not the right method to aim at effecting this dissipation directly in the furnace as three-phase power, rather than by the complication of first converting to single-phase power by rotating machinery? There undoubtedly is a demand for a single-phase supply for electric traction, and this demand will be enhanced to a very great extent in the near future if anticipated developments are fulfilled.

**Mr. W. B. Hird**: On the question of design there is just one point I should like to raise. In the balancer described in the paper under heading (5) there are two windings, one for single-phase and one for three-phase current. The windings are described as having the single-phase winding located so as to occupy the same sector as two of the three phases, and I would ask the

author what are the objections to distributing the single-phase slots so that instead of being coincident with two of the three phases they overlap one of the phases and half of each of the other two. It looks at first sight as if such an arrangement would be more symmetrical and in every way more easily dealt with. Turning to the practical applications of the paper, I would submit that it is to be hoped there will not be many occasions when the need to pass from three-phase (or any polyphase) to single-phase current will arise. So far as we can see at present the need for such conversion will be limited to supplies to furnaces or to traction load, and it is evident that the only circumstances which will require such a change from three-phase to single-phase will occur when both the load and the generating plant are small, for with a large number of furnaces or cars running it is easy to divide them equally between the three phases and to keep a sufficiently good balance for all practical purposes under all conditions of load. If, on the other hand, the system of supply is large it can stand a great many furnaces and cars, even if they are not equally divided between phases, without being put seriously out of balance. In these days of large undertakings when schemes are in hand for the erection of large stations or the interconnection of smaller ones, a combination of a small load and a small supply system will be infrequent, and a scheme of conversion can therefore only be useful in a very transitory way in a few isolated instances. It is perhaps as well that it should be so, for none of the schemes of conversion described by the author are really automatic. They all require skilful watching in order to make a successful combination, and they are all sufficiently complicated to require highly skilled attention. On these grounds, while I very much admire the paper from the theoretical point of view, I hope the occasions will be few when we have to resort to any of the devices described.

**Mr. F. Anslow:** If we admit, which it is not clear at the moment we should do, that the advantages of the single-phase furnace are sufficient to warrant the large expenditure necessary to balance the multiphase system from which the supply is drawn, then the data submitted will be of undoubted value and assistance in arriving at a decision as to the best system of balancing to adopt. It would have been an advantage if the relative advantages of the two types of furnaces could have been further discussed. It is not likely that as yet either type has attained to the highest possible degree of efficiency, and one inclines to the view that the tendency should be so to improve the multiphase furnace as to render unnecessary the single-phase furnace with its complicated and expensive balancing arrangements. Assuming a single-phase furnace to be necessary, the problem seems to be divided into two parts: first, to attain the necessary degree of balancing as efficiently and cheaply as possible; and, second, to use the plant required for other useful purposes, particularly for improving the power factor of the circuit. I gather that both these objects can be attained by means of a synchronous motor-generator, or by the special rotary balancer described by the author under section (5) of the paper, but I think that a closer comparison of the two systems might with advantage be produced. For instance, it is mentioned that the cost of certain balancing plant is only 65 per cent of that of a motor-generator for equal duty, but I am not clear that the balancing plant referred to is the special one advocated by the author. Again, the construction and windings of the rotary balancer appear somewhat complicated as compared with a straight-forward synchronous motor-generator. Also it would be interesting to know whether there is equally effective control with each system, particularly in regard to the degree of power-factor improvement possible. Such matters have their bearing upon the capital expenditure which might be justified in any particular case or set of circumstances.

**Mr. E. Seddon:** No doubt there are many advantages to be gained by the use of single-phase power, particularly in small furnaces. It is to be regretted that the author has found it necessary to introduce a rotating balancer to equalize the current in the three-phase lines, as this not only increases the cost of the furnace but introduces undesirable features from the consumer's point of view. As a rule consumers do not mind installing static apparatus which requires no attention, but they do not want running plant in their sub-stations if they can possibly avoid it. I should like to ask the author whether the small furnace up to 4 tons could be connected across one of the three phases without causing serious fluctuations in pressure. I believe the larger sizes are quite successful when supplied by three-phase current and controlled by automatic regulators. The electric furnace is essentially the class of load for a large station, and most supply engineers who have not yet handled this business will have to provide for it in the immediate future. It is of course a new industry and still in the development stage, and the future is bound to see improved designs of furnaces brought out which will probably wipe out the advantages to be gained by the use of single-phase current. Regarding the use of single-phase power for railway work, will the author please state why the three-phase two-phase Scott-connected system should not make quite an efficient method of supply with one phase for each track and the middle point earthed?

**Mr. J. H. Buchanan:** The idea of using a backward rotating field seems to be very attractive. I take it that it will require a good deal of care in the arrangement and running of this, and that the backward-rotating field must be in some particular position in regard to the forward-rotating field in order to balance properly. I should like to see how such a machine would work, and I should be interested to have one or two details with regard to its performance. It occurs to me that the stator of this machine contains a great deal of copper crowded together, and that there is a great mass of end windings projecting at the ends. I should imagine that the copper losses must be considerable, necessitating a fairly large machine. I think, too, it ought to be pointed out that these are special machines which have to be specially designed for the job. No doubt that is not much of an objection provided the furnace with which they have to work could be stan-

dardized as well as the machine, but if such machines are supplied to work tramways, for instance, the objection will hold.

**Mr. D. S. Munro**: The paper would have perhaps even greater everyday value if the author had given more indication of relative efficiencies—of the five modes presented—at varying ratios of supply capacity to load. The author claims for his machine a higher full-load efficiency and lower first cost than for the motor-generator. One fears that these advantages might be lessened in practice if allowance be made for skilled attention, increased difficulty of repairs, and complications ensuing from those unexpected, but inevitable, deviations from perfect balance which occur in three-phase lines. With the common motor-generator there is possibly a greater feeling of security that accidental eccentricities of supply are not positively transmitted further, but indeed tend to be corrected by the synchronous motor. The two types of load, where conversion to single-phase is assumed to be advantageous, are just those which will soon develop into the biggest things which even super-stations will have to tackle. The very maximum of efficiency of supply will have to be applied to both railway and furnace work; and instinctively one feels that a division rather than a conversion of the three phases will suit best the ultimate enormous loads. In the transition period, and for selected work, there is without doubt a place for the rotating balancing transformer, and the author is to be congratulated on this masterly inquisition on what is acknowledged to be an awkward link in the chain of electricity supply.

**Professor F. G. Baily**: The machine devised by the author is exceedingly ingenious, and gives a simpler device than the others he describes which have been evolved in America. It corresponds, in effect, to the well-known direct-current transformer, having a single field-magnet and armature core, with two windings on the latter; and, as the armature is stationary, the combination is neater than the d.c. form with its two commutators. There will be both dynamo action and transformer action on the secondary, and as the latter is harmful, presumably there is some device to check this. The combination in one machine of voltage transformer, choking coil, power-factor rectifier, and changer from three-phase to single-phase current is an achievement, and the efficiency is naturally high, as the same windings perform so many functions. Nevertheless, it must be noted that the whole power required passes twice through the windings. It is a motor-generator, and I should doubt if it is much cheaper than the two machines separately mounted. The latter will do all that the author's machine will do, for I take it that the power pulsation he discusses is really taken up in his machine by the momentum of the revolving field-magnet, as it would be in a motor-generator. The actual oscillation of power on the three-phase side will be small in either case. I am inclined to think that the direct conversion of three-phase to single-phase is to be avoided. In many cases it would be possible to use two single-phase circuits, and these can be easily provided by conversion of three-phase to two-phase. The probable inequality of the two circuits can be adjusted by an alternating-current balancer, i.e. coupled motor and dynamo, as in a d.c. three-wire system, and the machines, if synchronous and over-excited, would compensate in some measure for the requisite choking in the circuits. The balancer would in many cases be much smaller than the complete motor-generator, and the three-phase-two-phase transformer is cheap and very efficient. The chokers would require to be on the furnace side of the balancer, if the latter is to compensate the phase lag, and this makes the combination rather cumbrous to describe, but as each furnace would have its own choker, there is some advantage in this. In fact I do not see how the author's machine will supply current at a specified angle of lag to a variable number of furnaces. As the number of furnaces changes, so will the angle of lag, as the resistance varies and the inductance remains constant. It would seem that the machine is appropriate to places where a single furnace is used, and for this it has many advantages over the other methods that have been tried. At all events it is an invention of much interest in the domain of dynamo design and theory.

**Professor Miles Walker** (*in reply*): In reply to Mr. Mitchell, if the single-phase load on the three-phase generator does not exceed 20 per cent of the full-load rating, the heating, on a rotor of modern construction, caused by the pulsating flux will not be important. The running of arcs in parallel on a single-phase furnace can be carried out quite well if each of the arcs has an independent inductance in series with it, as shown in Fig. G (page 147).

In reply to Mr. Hird, the distribution of the single-phase winding so that it is opposite to phases A, B, and C has been considered, and is in fact described in my patent specification. In practice, it would lead to a rather more complicated compensating winding. Mr. Hird is wrong when he says that none of the schemes of conversion are automatic. I have pointed out in the paper those that are automatic and those that are not, and the amount of attention required is not more than is required with any running machine.

Mr. Anslow asks whether the control of the power factor with the rotating balancing transformer can be as effective as with a motor-generator. The two kinds of plant are identical in this respect: the rotating balancing transformer acts as a synchronous motor, and by over-exciting it the power factor can be made unity or leading, as required. There is nothing complicated in the winding of the balancer; a motor-generator would have the high-tension winding on one stator and the low-tension winding on the other stator; the balancing transformer has both windings on the same stator, so that only one field-magnet is required. The ampere-turns on that field-magnet are somewhat diminished by reason of the fact that the three-phase armature to a certain extent neutralizes the action of the single-phase armature. The cost of the balancer should be about 70 per cent of the cost of a motor-generator, and the efficiency of the 500-kw. size would be about 5 per cent better.

The use of a three-phase—two-phase Scott-connected system supplying a single-phase railway has often been

proposed, and it will produce a balanced system so long as the loads on both sides of the neutral are balanced. Although it is not in practice possible to keep both sides in perfect balance, the employment of two phases on different parts of the system is quite a feasible proposition, as stated in the paper.

Many of the speakers seem to forget that in electric furnace work the stabilizing of the arc is of enormous commercial importance; and the only satisfactory way at present known of stabilizing the arc is to put a big reactance in circuit with it. It has been abundantly proved that the addition of this reactance is a great source of economy, inasmuch as it saves furnace linings. Once we admit the desirability of the reactance, we must see what can be done to correct the power factor for the benefit of the power station. This is best done by means of a synchronous motor. If now we have a synchronous motor and a reactance, there seems to be no reason why they should not be combined with the transformer, which will in any case be necessary.

In reply to Professor Baily, it is quite possible to build a balancer with the winding arranged so that it can supply any number of furnaces. The single-phase winding in the balancer described has eight circuits in parallel, and each of these circuits has the right characteristic in itself; so that any of them can be employed separately, or any number can be connected in parallel without affecting the shape of the load-ampere curve given in Fig. 23.

## North-Western Centre, at Manchester, 28 January, 1919.

**Mr. W. E. M. Ayres**: The author has referred to the balancing of the phases by means of static condensers. These have been very much improved in recent years and can be produced for large outputs at a reasonable cost, if not of a reasonable bulk. They are quite reliable and extremely efficient, but they are not flexible without a lot of switchgear. It is pointed out in the paper that if a static condenser is used to bring about the balancing of the phases, when we throw off the unbalancing load the circuit is equally unbalanced in another direction. That is a rather serious proposition. If we have many furnaces and use static condensers it will mean either a good deal of switching in and out, or else the load will be alternately balanced and unbalanced in various directions. I have recently come across an instance, in connection with a colliery plant, of static condensers which are being discarded in favour of synchronous rotating machinery. I suspect that the lack of flexibility referred to is responsible for the change. With regard to electric furnace work, considerable difference of opinion exists as to the relative merits of single-phase and polyphase practice. Perhaps the author will be able to give us some more information on this point; as far as I understand, one of the limiting features of furnace work is the amount of power which can be used per electrode. At present the size in which the electrode can be made is a limiting feature. I think it is something like 16 inches or 18 inches square for compressed coke electrodes, and about 12 inches for graphitic. This means that at the ordinary pressures adopted, i.e. about 85 volts, 400 kw. per electrode can be used. If we employ the single-phase furnace and are able to as much as double the voltage we are limited to 800 kw. These would be quite small furnaces suitable only for refining, and would stand a poor chance against polyphase furnaces using 3, 4, 6, or 8 electrodes. I do not know whether I am right, but it seems to me that for an electric blast furnace the single-phase type will be quite out of the question. If a multiplicity of electrodes can be employed with a single-phase furnace, why not a multiplicity of phases? If then we are limited to furnaces of 400 to 800 kw. capacity I do not know whether a machine of the construction described by the author is going to be any great advantage or in great request. He mentioned that at Bradford they allowed 400 kw. of unbalanced furnace load without seriously disturbing their system. How little then will be the effect of 800 kw. on the promised super-power stations? If the furnaces are multiplied in number and thrown on different phases the balancing can be fairly well arranged. It is quite true that in this country the balancing of single-phase load upon a three-phase circuit has received little attention, but in America, where single-phase traction has played an important part, the question has been closely studied and a very large number of patents taken out for different arrangements of balancing. In most of these a comparatively small rotating balancing machine, which can be a simple three-phase squirrel-cage motor, in conjunction with transformers provided with suitable tappings, is all that is required. It seems to be that this should work out cheaper than the balancing transformer described, inasmuch as it only deals with the unbalanced portion of the load and has a single winding. It will bear the relation of a booster to a generator, or an auto-transformer to a double-wound transformer. This seems to be the case from the dimensions of the machine described, which has a value of $D^2 L$ about 80 per cent more than would be required for an ordinary synchronous generator. The author gives its cost as something like 65 per cent of a motor-generator set. I presume that the machine described is limited to furnace work on account of the very high reactance of the single-phase winding, due to its position and the form of the slot.

**Mr. S. Chadwick**: On referring to Figs. 5 and 8 in the paper, it will be noticed that the boosting effect is obtained by means of shunt transformers. I should like to point out another method whereby the boosting has been proposed to be done with a series arrangement. Referring to Fig. 11 herewith, A B represents the primary of a transformer taking single-phase power. $S_1$ and $S_2$ represent the secondary windings of the transformer. C O, D O, E O, represent the windings of a balancer which may be synchronous or asynchronous (if the former it must be fitted with a damper) and F O, G O, H O, represent the windings

of the load, say a three-phase induction motor. With D and G disconnected, and the ends of $S_1$ and $S_2$ connected respectively to C F and E H, the windings F O and O H will receive single-phase power, and the motor, if started, will run as a single-phase induction motor. The synchronous motor, D C E, will also be operating as a single-phase motor and an electromotive force will be generated in the winding D O. If, now,

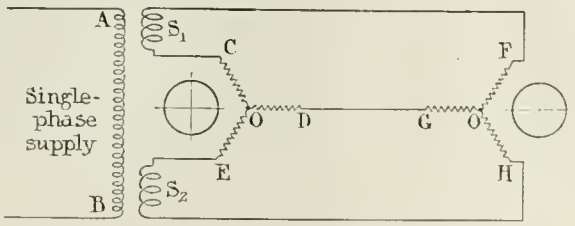



FIG. H.

D and G be joined, F G H will be fed also through G O, and it will run as a three-phase motor. As the induction motor is loaded more current flows through C O E, and the increased ampere-turns of the revolving field produce a greater current in D O, giving the increased boosting effect in G O in series.

**Lieutenant F. C. Lawrence**: Mr. Chadwick has referred to the series transformer. The function of that transformer is to develop the electromotive force in proportion to the current. From Fig. 11, it will be seen that the choke coil X Y gives an electromotive force proportional to the current in the line, that is, proportional to the load. Again, on page 125 the electromotive force generated in the compensator coil is proportional to the leakage from the single-phase winding, i.e. proportional to the current in the single-phase-winding—the load. This also acts as a current transformer.

**Mr. R. Shaffer**: I should like to draw attention again to the part which the static condensers play in the balancing action (see the diagram on page 134). Condensers are very unsatisfactory apparatus, for they give constant trouble and need constant watching, besides being costly. The author has also suggested the use of rotating machinery in the shape of synchronous motors, in place of static condensers. The motor will be connected across the terminals of the transformers, instead of the condenser shown, and its field normally excited when there is no load on the furnace. Arrangements can easily be made by means of a suitable regulator so that, as the load comes on, the field of the motor is over-excited, the amount of over-excitation depending upon the extra load. This will cause the motor to take a leading current, and thus provide the balancing effect that is necessary. The whole balancing is thus purely automatic and exceedingly simple. Balancing by the condenser method necessitates complicated switchgear, as condensers must be switched in and out as the load varies. Thus I think that to use over-excited synchronous machinery in place of static condensers is a much better method.

**Mr. G. J. Stock**: I should like to make a few remarks in connection with the purposes for which the first of these phase-balancing machines has been built. A previous speaker has mentioned the question of whether single-phase power would be useful in large units, the idea being that the possible size of the electrode would largely control the amount of current which could be put into the furnace. That is perfectly correct, but, in the system which Mr. Synder has introduced, a rather high voltage is used and this enables us to employ quite a large amount of power in a single electrode. I do not think that at present there is any reason why the furnace should not be built to use, say, 2,500 kw., which would mean approximately 15 tons' capacity. I should here like to lay down this condition, which I think should be accepted by all people when considering the application of the electric furnace to steel making, viz. it is now quite evident that any furnace which will work at all will make equally good steel. I entirely disagree with any claim that either a polyphase furnace or a single-phase furnace will make a better quality of steel one than the other. If that be the case, it is obvious that the steel-maker has to look to economy as the only guide for the selection of a furnace. Economy can be brought about in three directions. First of all, the condition that the steel-maker looks for is a fairly economical power consumption. Secondly, he examines his electrode consumption. Thirdly, there is the cost of maintaining the linings. Apart from those things and good mechanical engineering in the plant, I do not see that there is very much else to consider in any type of furnace. As regards the first item, power consumption, it is quite evident that this factor is governed, first of all, by the amount of heat losses of the furnace and, secondly, by the quality of the refractories in the lining of the furnace. With no heat losses and refractories which it is quite impossible to melt, any type of electric furnace at present known will naturally use the same amount of power per ton of metal produced. This brings us to the consideration of the right position to introduce the heat in a furnace. This is obviously in the metal itself, which can only be done in an induction or resistance furnace. In the arc type of furnace the obvious position to introduce the heat is in the centre of the furnace because, as the heat travels towards the outside, it is absorbed as much as possible by the charge in the furnace. For that reason Mr. Snyder—and I agree with him—is a believer in the single-phase system. The second point is the electrode consumption. It is clear that if we can reduce the diameter of the electrode exposed to the gases in the furnace we reduce its area. This result is arrived at by using a high voltage. The electrode consumption is governed by the amount of oxidation which takes place in the furnace itself, and this principally occurs during the time of charging. I believe it can be shown that the volatilization of carbon in an electric furnace is under 1 lb. of electrode per ton of metal. The installations that we have built for single-phase work have shown that it is quite possible to operate a single-phase furnace of 400 kw. capacity making, say, 50 to 55 tons of metal per week, with an electrode consumption of under 6 lb. per ton of metal produced. Graphite electrodes to-day cost one shilling a lb., so that is undoubtedly an item which has to be considered in choosing the type of furnace to be

used. The third point which must be considered is the life of the linings. The author has said something about that. It is perfectly true that the life of the lining is entirely dependent upon our control over the consumption of power in the furnace. Given proper control there is no doubt that the linings can be made to stand up for quite a long period. We have at present four furnaces operating in Bradford and they are able to produce at least 200 tons of steel per roof, and with an inside veneer of lining they are able to work for a week without any repair whatever. These results have produced a very good load factor on the furnace. As a matter of fact it happens to be somewhere about 60 per cent. The method we use for arriving at the load factor is to take a full week of seven days and multiply the number of hours by 400 (the author has shown us we cannot use more than 400 kw.). We divide that by the number of units which have been used to produce the steel during the week: 55 tons multiplied by 700 units. This gives a load factor of 57·3 per cent. Those are the only considerations which I think one would be justified in regarding in the choice of an electric furnace. There is one objection which has been raised in this country to the Snyder furnace or the single-phase furnace when refining is the object of its operation. With arc furnaces the theoretical considerations which govern the desulphurizing of the metal are these: It is necessary to produce a bath which is entirely deoxidized and has strongly limy slag above it. To achieve this condition we must have a very high temperature and it, as will occur with the Snyder type of furnace, we were to try to carry out our refining operations with the full load, that is, at 160 volts pressure, we should very soon find that the arc became entirely ionized by the calcium and drawn out possibly to the extent of 18 or 24 inches. The drawing out of the arc must naturally throw the heat from it in the direction of the sides and roof, and the silica parts of the furnace would melt down and spoil the refining operations. It has been found necessary, therefore, for refining operations, to work with an arc of not more than 80 volts pressure to prevent this pulling out and to concentrate the generation of heat on the slag itself. To arrive at this result the author has given us a separate tapping on the phase balancer, which allows us to reduce the voltage to this figure and to maintain a sufficient input to keep the bath hot, and we find under these conditions that desulphurizing is a perfectly feasible operation.

**Mr. W. B. Shaw**: The electric furnace at present affords one of the most promising fields for the development of electric power and of heavy electrical appliances, and any machine or device which, by improving the efficiency of the furnace or the results obtainable from it, assists in that development should be welcomed by electrical engineers generally. There is no doubt that the single-phase furnace is an attractive proposition from the steel-maker's point of view, and an unattractive one from the supply engineer's. When the Snyder furnace was first introduced into this country there was great reluctance on the part of central station engineers to consider furnace schemes which would entail running, even for short periods, single single-phase furnaces off the three-phase supply, although I believe that in America the power companies raised no such objection. Experience at Bradford has shown, however, that no practical difficulty actually arises where the capacity of the generating plant is large in proportion to the capacity of the furnace adopted. The author has shown in Fig. 23 how in the Snyder furnace the kilowatts rise to a maximum and then decrease, but it should be kept in mind that the kilovolt-amperes continue to increase up to short-circuit, and if the reactance in the circuit has not a straight-line characteristic the maximum kilovolt-amperes may rise to as much as twice the k.v.a. corresponding to maximum kilowatts. During the melting-down period short-circuited conditions frequently occur for short intervals, with the result that the maximum k.v.a. value on which the consumer is charged approximates to that at short-circuit. This, of course, refers to furnaces supplied through a transformer and reactance as shown in Fig 20. With the author's machine installed instead, the maximum k.v.a. value is only about 10 per cent greater that the maximum kw. value up to short-circuit conditions, and it is in this respect that the machine chiefly appeals to the consumer. The application of the Miles-Walker balancer to two cases may be considered. First, where the steel-maker is desirous of making steel electrically on a moderate scale and only contemplates the installation of one single-phase furnace. If he has the resources of a large supply system to draw upon for power, he may be able to prevail upon the supply authority to supply him off a pair of phases, but as his maximum k.v.a. charged will be reckoned as though all three phases were loaded up with the maximum current, he will have to pay for $\sqrt{3}$ times his actual maximum k.v.a. Even if his furnace works day and night the effect of this heavy k.v.a. charge will be to put up the cost per unit to a figure which will probably make the cost of production too high for the furnace to be commercially successful. If he has only his own works supply or that of a comparatively small supply system to draw upon, the proposition of a supply from a pair of phases becomes impossible owing to the disturbing effects. In either case, therefore, if he desires to retain the advantages of the single-phase furnace from the steel-making point of view he is driven to put down machinery for converting from three-phase to single-phase, and the choice lies between a motor-generator with a reactance in the generator circuit and a Miles-Walker balancer. The advantage as regards capital outlay, efficiency, and floor space occupied will lie with the balancer. In a project recently considered for a 450-kw. furnace, a comparison between working off a pair of phases of a large municipal supply and working with a balancer showed a saving in the cost of power, after allowing 12½ per cent for interest and depreciation, of £800 per annum for day and night working, and of £900 per annum for day working, by the use of the balancer. The second case is that of an approximately balanced installation of three furnaces, or two working Scott-connected. If the source of supply is of comparatively small capacity, the case

from the point of view of disturbance of the supply is similar to that of one furnace, because there will frequently be periods when only one furnace is working, and here the balancer makes the proposition a feasible one. If the source of supply is large, the objection on the score of disturbance ceases to apply and the maximum k.v.a. charge is not prohibitive because it is based on the actual maximum and not on $\sqrt{3}$ times the actual. The case for the balancer therefore resolves itself into a comparison of the interest and depreciation on the cost of three balancers with switchgear, as against three transformers with reactance and switchgear; the power cost of losses in the balancers as against those in the transformers and reactances; and the maximum k.v.a. charge in the two cases. In a case recently considered of three furnaces of 450 kw. capacity there was a slight advantage in favour of the balancer, amounting to about £200 per annum for day and night working and about £300 per annum for day working. I understand that the author's machine can be designed to give an adjustable leading power factor. Another way therefore in which the balancer may effect a saving in the cost of power is by the correction of the general power factor of a works supply. In a case recently considered of a works with a three-phase motor load of 500 kw. having a power factor of 0·75 with a balancer designed to correct this power factor to 0·95, the net saving per annum by reduction in the maximum k.v.a. charge for the motor load, after allowing for interest and depreciation on the increase in cost of the balancer designed for these conditions and the cost of power for increased excitation, worked out at approximately £100 per annum. Two points in which the balancer is at a disadvantage as compared with a transformer and reactance are: (1) the reliability of the installation depends on running machinery as against static apparatus; and (2) the possible range of adjustment of the amount of reactance in the single-phase circuit appears to be much more limited than can be arranged in the reactance used in conjunction with a transformer. This latter point is of some importance where experimenting has to be done in a new method of working, where a new size of furnace is being tried or a different product is being made, for at present there appears to be no finality as to the best furnace conditions and methods of working to produce steel or other metal of a given quality. A point in connection with the Snyder method of working with heavy reactance in the circuit which is not always appreciated is the fact that the voltage is "elastic." This is of considerable advantage in the melting-down period, because the resistance through the loose pieces of metal or shavings is constantly varying as the pieces melt or fall away or settle down closer. By the action of the reactance, a rise or fall in resistance is immediately countered by a rise or fall in voltage, the effect of which is to speed up the melting period and at the same time prevent excessive current peaks in the supply.

**Mr. J. F. Shipley:** I want to make a few remarks about an aspect which engineers in this country do not often consider, namely, that Professor Walker in particular, and some other authors of papers, very often provide us with new points of view. For instance, I have a large amount of business to do with the undeveloped countries of South America, particularly Bolivia. In those countries if we could have obtained a machine like that described in the paper we should have been able to do something which was most difficult to do during the war. We have not been able to obtain any machinery from England, and the consequence is that Japanese, Swedish, and American machinery has been pouring in. In Bolivia the circumstances and the practical problems are quite different from those in this country. For instance, the cost of plant does not matter very much, because transport costs are sometimes three or four times the cost of the plant; the main consideration is whether one can do the work. We generally can do it with electrical machinery where we cannot do it with anything else. I should like to hear further particulars from people who have been using static and synchronous condensers for correcting power factor and balancing machines. There have recently been two cases where we could have used them successfully. Bolivia is a country which is at an altitude of 4,000 metres, and the Diesel oil engine is the only motive-power we can employ. The cost of coal—even before the war—was about £25 per ton, and the only other fuels are llama dung and a resinous moss growing on the mountain-side which is mostly exhausted. We use water-power when we can get it, but it is generally not of much value because it is so far distant and in such remote regions that transmission lines cannot be run; there is no one to do the work. We installed a 6-cylinder Diesel engine of about 450 h.p. (at sea-level) coupled to a three-phase alternator for mining work. This engine of course was only able to give about 280 h.p. at that altitude because of the reduced oxygen content of the air, and we had provided an alternator that would utilize the whole of the power of the engine at that altitude. Then we had a complaint from the manager of the mine saying that the engine was much too big for the rating or, vice versa, the alternator too small. I have good reason to believe the position was this: He had three-phase induction motors driving various mining plant. This was the first run and the alternator was loaded up with all the motors that could be obtained. Some motors were undoubtedly run on no load, and the power factor of the total load must have been very low. The complaint was that the alternator was overloaded with current, which the engine was capable of supplying when working with only a few cylinders. We wanted leading current to counteract the lagging current. If we could have obtained a static condenser, or a machine of that sort, we should have been able to alter the position altogether. We have had that sort of trouble on more than one occasion out there. Papers like this shed a little light upon such problems. May I ask the engineers of this country to pay more attention to these new fields in the export world? Very few manufacturers in this country realize that there are huge fields abroad which at present they do not touch. The only enterprising people in this country seem to be the cable makers; they are the only firms who send out representatives to travel in those countries. During the war we have been swamped with Americans and with Japanese,

and we have had the Germans always with us, but we have never had a single English firm worrying about business in Peru, Chili, or Bolivia. I wish members would pay a little more attention to these countries, because now is the time. This matter should interest those designers of machinery who have the idea that the only conditions they have to fulfil are those of this country. The Germans did so well because their machinery was not designed so much for their own trade as for their export trade. I have had the greatest difficulty in getting British manufacturers to alter their designs, or modify them to enable us to sell them. We cannot sell them merely because they are suitable for British mines: our circumstances are quite different.

**Dr. W. Cramp:** The subject of the paper may be divided under two heads, viz. general remarks upon the characteristics of steel furnaces, and a discussion of the design of the author's special balancing converter. In the preliminary remarks upon the methods of obtaining single-phase power, I do not understand why a rotating balancer with transformer has not been considered. Such a machine would take the three-phase power into one winding and give out single-phase power from the same winding, the latter being transformed by means of a static transformer. It would be interesting to know whether such a combination would not be cheaper than the combination mentioned under (5). In connection with the question of single-phase versus polyphase furnaces, I should like to point out that the disadvantage which the author mentions of a breakdown across the top of the furnace—due to the potential difference between the pair of carbons situated there—is offset to a certain extent by the ease with which the polyphase furnace can be started, and the complete freedom from those troubles at the bottom electrode which are known to occur in single-phase furnaces and which have caused, I believe, in some cases serious explosions. Thus in a polyphase furnace the existence of the potential difference between the electrodes enables a cold charge to be gradually melted down while the bottom or neutral conductor is practically non-conducting. When the metal is once melted and the bottom is hot, the current will pass partly between conductors and partly through the metal to the neutral, giving uniform heating and rendering it possible to use the whole furnace bottom as the neutral pole, instead of the localized single-phase bottom carbon. The author also points out that in the single-phase furnace the voltage between the terminals can be raised to almost double that which is practicable for a polyphase furnace. I believe that in future the electric furnace will be used much more for refining than for breaking down; and if that is so, the advantages of the high voltage very largely disappear. I do not wish to minimize the possibility of making use of the single-phase furnace for particular cases, but it seems to me that both its use and its size will be limited by its characteristics. I should like also to add that the figure given to-night of 2,000 kw. for a 15-ton furnace can be equalled with a polyphase furnace, but the figure is useless unless accompanied by data as to the charge and the quality of the finished steel. The author's argument in connection with Fig. 23 is very interesting, but power-station engineers with whom I have had to deal in connection with these furnaces have generally complained not so much about the large fluctuations of power as of the large fluctuations of current; that is to say, if the current is largely wattless they still complain if there are large fluctuations. From the point of view of the power-station engineer then it would seem that a constant-current machine would be at least as valuable as a constant-power machine. The author next refers to the use of automatic regulators. He says: "Automatic regulators are often installed to keep the current within bounds,"—he does not refer to the power—"but even these are not found to be sufficient during the first 20 minutes after the furnace has been started up from cold." I think it is evident that the author of the paper has not seen the regulator which has been recently introduced to cover that very point. The regulator works in such a way that the moment the voltage between the carbons falls below a certain pre-determined figure the carbons are raised, so that the length of the arc is increased and the voltage is again restored. That goes on until all the material is molten, when the ordinary Thury regulator comes into action. By this device the furnace becomes entirely automatic. The only condition under which this regulator is not very satisfactory is in connection with new carbons. New carbons are apt to split the first time they are heated, so that it may be necessary to make the regulation a little more gentle under these conditions. I pass now to a consideration of the author's special converter and should like to congratulate him particularly upon the very ingenious method of compensating for the reactance of the alternating-current winding by means of that small winding through which the leakage flux is passed. Directly I saw Fig. 24 I remembered a machine that I made some years ago for quite a different purpose. The lower * slots contained an ordinary induction motor winding, and the upper slots a repulsion motor winding. The result was that at starting, when the rotor frequency was high, the top winding carried most of the current and the machine would start as a repulsion motor. As the frequency in the rotor got lower the induction motor winding became more and more effective, so that the result was a single-phase motor with good starting and running characteristics. In calculating the leakage through the compensating winding the author has referred to Appendixes 7 and 8 and to his book. I could not find that the system of calculation for the slot leakage was very evident in the book, but leakage calculations are now so very important that there is a really good reason for going to some trouble to work them out exactly. In the case under consideration we have a slot of the form shown in Fig. 1 whose surface A B C D may be assumed to be at a magnetic potential which is constant from B towards D. This magnetic potential I denote by + P. Similarly the magnetic potential along the corresponding opposite surface of the slot F G K may be denoted by − P. It is easiest to consider the flux existing between either of these surfaces and the median line L M which is at zero poten-

* By "upper slot" is meant the slot nearer to the air-gap.

tial. Treating the case as a problem in two dimensions by the ordinary methods it is easy to calculate either the exact magnetic density at any point, or the exact value of the flux between any two planes at right angles to the plane of the diagram. If $2h$ be the width of the narrow part of the slot, and $2H$ the width of the wide portion, it appears that the flux density from C towards D quickly becomes uniform if $h/H$ is small; but otherwise the fringing of the lines of force has an important result. In the author's case it is not of importance, but if, for instance, $h/H=\frac{1}{3}$ it may be shown that over a distance from C towards D $=0{\cdot}1\,h$ the flux will be at least 50 per cent greater than if calculated on the basis of a uniform density. Thus when $h/H$ is of this order the flux should be worked out accurately. It is, however, of greater interest to calculate the flux from the face C B. This may be shown to be

$$l\frac{P}{\pi}\log_e\left(\frac{h}{H}\right)^2 = 1{\cdot}46\,l\,P\log_{10}\frac{h}{H},$$

where $l$ is the axial length of the slot in centimetres. It would be out of place to develop the matter further in this discussion, but the above formula is of interest for many

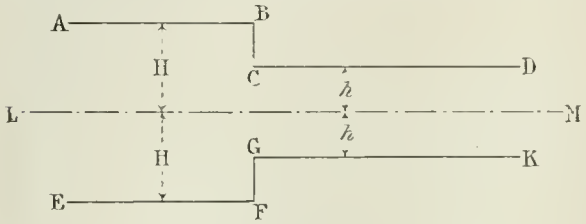



FIG. J.

cases besides that of the paper; and it is so simple as to be more easy of application than many of the usual approximations. I should like to congratulate the author upon what has been a difficult machine to arrange and is an excellent example of design, and also to ask a question about the behaviour of the machine on load. One trouble in connection with electric furnaces is that the current is liable to swing about, and there may be temporary or partial short-circuits. These swings of the current are liable to set up very high pressures, particularly in the final turns of the transformer winding. I should like to ask the author whether he has taken any particular care in insulating the machine to avoid those troubles. There is very little said in the paper about insulation, but it is one of the most important points both to the designer and to the user. Finally may I remark that on page 125 the author says: "It was found that with this arrangement the damper showed no signs of heating at no load and only very slight heating at full load." Is not that rather a condemnation of the damper? If the damper really never got warm it was either carrying no current and therefore unnecessary, or there was more copper in it than the circumstances required.

**Mr. W. H. Lea** (*communicated*): I recently had the opportunity of seeing the synchronous balancer at work at Darlington. I was very pleased with the design and with the performance of the machine. The staff had nothing but praise for it. It was supplying current to a single-phase Snyder furnace with one upper electrode, the return being through a steel electrode in the hearth, which was water-cooled, an arrangement which I cannot say I approve of. When the metal has been run off into the ladle a rather deep conical depression is left in the furnace hearth, and while the furnace is still at a white heat a steel peg has to be inserted in the molten end of the bottom electrode and the furnace bottom fettled up to the correct shape. I was rather disappointed that I could not see the machine tested on short-circuit, but I was told that it was frequently done without any harm resulting. I am sorry to say that, although the single-phase furnace at first sight seemed very attractive, I am convinced the advantages of this type are more apparent than real. The question must be looked at not only from the electrical point of view, but from that of the metallurgist. From the electrical standpoint the increased voltage of the long arc enables us to supply the same energy with half the current. While this is perfectly suitable for melting down metal without changing the composition, as was done at Darlington, if the metal requires refining we must have a short arc with more area or surface than the single-phase type. In my opinion the furnace would be improved, and be more adaptable, if both electrodes were placed above the bath of metal, thereby eliminating the objectionable and dangerous bottom electrode. I have also been fortunate in seeing the three other types of furnaces at work. The three types were the Héroult with three electrodes all above the hearth working simple three-phase, the Greaves-Etchells with two electrodes above the hearth and the third phase working through the hearth and supplied by a special transformer, and the Electro Metals with two electrodes above the hearth supplied with two-phase current by Scott-connected transformers from a three-phase supply, the hearth being conducting and forming a common return for the two phases. I cannot see any essential difference in the three types from the melting point of view; they all seem to work equally well, and all the users are satisfied that they all have the best furnace. I am told that the slag on the surface of the metal must be higher in temperature than the metal in order to refine successfully. Owing to the large surface of arc in contact with the metal, the refining is very rapid in these furnaces. The makers of two of these furnaces claim a rotation of the charge; this may be so, but I am not altogether convinced. In the Héroult furnace, metal has been melted and refined with quite as small a consumption of energy as in the other types. The author claims 650 units per ton of steel. This must be for melting only, as the average consumption, as far as I can ascertain, for melting and refining is 780 units per ton. In some cases for melting alloy steels, 900 to 1,000 units are required. The success of the electric furnace has chiefly been attained on alloy steels. It is much more difficult to compete with the Siemens open-hearth furnace in the production of low-carbon steels. If steel is wanted in large castings, there is no possibility of competing with the open-hearth furnace with electrical energy at the present price, but if small casts are re-

quired at short intervals, then it would be advisable to use the electric furnace. With regard to the furnace of the future, the tendency seems to be leading up to multiple-arc furnaces for the larger sizes. We may therefore expect in the future large furnaces with six or more electrodes arranged to cover the whole surface of the metal and melting and refining very rapidly indeed. These could be supplied with three-phase current, with two arcs on each phase, each electrode having its own transformer, and coupled Y with the neutral on the hearth. It is essential that the transformers be single-phase and all of the same size and pattern; if this were done any transformer could be replaced by a spare one, in the event of failure of any one of them, and the furnace got to work again in the shortest possible time. There is, of course, a serious loss of heat through the holes in the roof for the electrodes, but this will be reduced in the future by properly designed economizers.

**Professor Miles Walker** (*in reply*): Mr. Ayres has assumed that only one carbon can be used in a single-phase furnace. As already pointed out, it is possible to use any number of carbons in parallel, and the possible input into the furnace is therefore unlimited. The advantages and disadvantages of the other types of balancers are fully considered in the paper. It must be remembered that in any case it is necessary to transform from a high voltage to the voltage of the furnace. The cost of a transformer and balancer together with the necessary adjuncts is more than the cost of the balancing transformer and its adjuncts.

I am greatly obliged to Mr. Bolton Shaw for the figures of cost that he has given. He speaks with the authority of a man who has considered the figures in detail. He shows that even if three separate balancers and switchgear were employed in the case of three furnaces, there is still a saving of £100 per annum over the cost of the method using transformers only. It would be quite possible to build one balancer to take the three furnaces; this would be much cheaper and would give even better results.

Dr. Cramp has evidently not observed that the type of balancer that he mentions is fully described in the paper, and its advantages and disadvantages discussed. It is a mistake to suppose that there is trouble with a modern single-phase furnace owing to the bottom electrode. All furnaces have gone through their experimental stages, and in the early days some accidents happened; but where proper provision is made the furnace is started with very great ease, and no trouble is experienced from the water-cooled electrode at the base of the furnace.

The increase of current on short-circuit to 1·4 times its full-load value occurs in the furnace, but not on the high-tension side of the balancer. If Dr. Cramp will look at the short-circuit test figures on the test sheet, he will see that the high-tension amperes are less on short-circuit than on full load.

Referring to Fig. J, a more usual plan for estimating leakage is to estimate the density not on the surface A B C D but on the surface L M. It will then be seen that the density on L M at a point midway between C and G is less, and not greater, than the density at a point midway between D and K; in fact, the tailing-off of the flux density towards the end of the narrow part of the slot is almost exactly compensated for by the increase in the density on the surface L M as we pass from A towards B. So much so, that for all practical purposes it is sufficient to take the density in the wide part of the slot as if it were uniform from A to B, and the density in the narrow part of the slot as though it were uniform from C to D. The error in so doing is so small in the machine in question that one would not be justified in spending time upon the more exact methods that have been worked out by Mr. W. F. Carter. Nevertheless, I heartily agree with Dr. Cramp as to the advisability of accuracy in calculation.

With regard to the insulation of the machine, I may point out that the two coils nearest to the terminals of the machine had very-high-voltage insulation between turns, in order to minimize any risk from breakdown owing to electric waves emanating from the switches. In judging the temperatures to which one would expect the damper to rise, one must have regard to the fact that the cooling conditions of the damper are fairly good; and it is not advisable to make the losses in the damper so great as to give it a high temperature rise under these good cooling conditions.

# PROCEEDINGS OF THE INSTITUTION.

## 621st ORDINARY MEETING, 23 JANUARY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 9th January, 1919, were taken as read, and were confirmed and signed.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

*Benevolent Fund* :—A. W. Adams, H. Alabaster, G. A. Allan, P. R. Allen, C. E. Allsopp, Major R. Amberton, D. C. Andrews, O. M. Andrews, T. C. Angus, Lt. B. Atkinson, P. C. Austwick, H. J. Aylott, C. J. Baker, F. G. C. Baldwin, F. J. Baldwin, E. Balmford, P. E. Bamford, B. Barber, A. S. Barnes, P. J. Barnes, H. E. I. Bax, M. Beales, J. F. M. Bennett, J. C. Bentley, H. H. Berry, E. J. Black, C. W. Boxall, E. Braathen, I. Braby, H. P. Bramwell, E. Brierley, S. K. Broadfoot, R. A. Broster, W. Brown, W. H. Brownjohn, J. H. Buchanan, G. M. Burnand, S. Burns, R. B. Burrowes, P. H. C. Butcher, W. M. H. Butcher, Sir T. O. Callender, A. Campbell, Major E. D. Carden, R. S. Carlisle, J. McIlvaine Cater, J. W. P. Chalmers, W. A. Chamen, F. J. Chapple, D. S. Charles, A. H. Cheeseman, H. Cheesman, R. C. Graham Clark, E. F. Clarke, F. C. Clarke, B. C. Clayton, H. W. Clothier, F. G. Cole, A. Collins, A. D. Constable, W. W. Cook, K. Coombs, M. K. Cooper, W. Cotsworth, L. C. Cox, J. Coxon, F. W. Crawter, Captain E. W. Creak, C. Crompton, A. S. Cross, W. Cross, L. H. Crowther, A. Cunnington, J. S. Dalgleish, J. D. Dallas, K. Davidson, F. E. Davies, J. Davies, E. A. Deacon, B. P. Deane, E. E. M. De Boissière, Sir A. Denny, Bart., Major C. W. de Roemer, T. J. Digby, A. O. St. J. Dixon, I. T. Dixon, W. Dixon, C. M. Dorman, Dr. C. V. Drysdale, J. W. Eastwood, A. C. Eborall, K. Edgcumbe, J. H. Edwards, H. J. Eley, F. F. Elliott, E. de B. Elphick, E. Fawssett, H. S. Fellowes, W. O. Fenwick, J. H. Field, F. Flanagan, J. Flanagan, G. H. Fletcher, R. H. Fletcher, W. S. Flight, H. S. Fox, W. G. France, D. J. Gadsby, J. Gibbins, H. W. Gilbert, H. Gill, M. McA. Gillespie, T. Gladdy, E. A. Gordon, B. B. Granger, J. E. Grant, H. J. Grapes, E. B. Gray, H. W. Gregory, W. G. Griffith, L. Griffiths, W. C. J. Halford, R. Hardy, A. J. Harrison, C. J. W. Hanson, F. De B. Hart, J. B. Hartley, F. N. Haward, F. B. O. Hawes, W. C. C. Hawtayne, H. Hazelwood, W. G. Heath & Co., R. G. Heaton, Killingworth Hedges, W. T. Henley's Telegraph Works Co., Ltd., D. Henriques, H. J. Hindom, H. Hirst, W. E. Hobbs, L. B. Hobgen, N. J. Hockley, W. Hodson, P. M. Hogg, W. A. Hole, T. Holmes, A. V. Hopkins, B. F. Howard, E. G. Humfress, R. W. Humm, C. G. Huntley, A. Imbery, H. A. Irvine, G. G. Jacob, E. W. James, W. L. James, A. M. Jenkins, C. J. Jewell, C. E. Jones, H. W. Jones, I. Jones, J. W. Jones, P. C. Jones, H. D. Kemp, Sir A. B. W. Kennedy, H. E. M. Kensit, A. W. Kimber, H. F. A. Kinder, W. N. Y. King, H. Kingsbury, J. R. Kingston, H. W. Kolle, V. R. Krohn, W. Lang, T. Langlois, F. A. Lawson, W. H. Lea, H. B. Lee, L. J. Lepine, E. W. Lewis, H. J. Lewis, J. W. Lincoln, A. Lisle, G. S. Lisle, H. R. Lloyd, T. H. Lloyd, A. C. Lowe, A. McClelland, A. P. McDouall, G. M. Macilwraith, T. H. McNaught, H. McNaul, McWhirter & Sons, Ltd., C. W. Mallins, Sir H. C. Mance, E. Manville, Professor E. W. Marchant, J. Marshall, J. Martin, P. M. Martin, T. D. Martin, J. M. S. Maxwell, R. N. Mayne, Sir Spencer Maryon-Wilson, Bart., J. W. Meares, R. G. Mercer, L. G. E. Metz, P. Miley, H. William Miller, H. Woodville Miller, J. A. Miller, T. H. Minshall, W. J. Minton, A. Miskin, J. F. Mitchell, A. Morris, A. T. Morris, W. M. Morrison, G. W. Munday, A. R. Murray, J. C. Murray, F. D. Napier, A. J. Newman, G. A. Newsome, J. F. Nielson, A. M. Niven, C. G. Nobbs, A. C. Norman, W. H. Nottage, P. de O. Novaes, V. F. M. Oliver, B. S. Orme, A. S. Padgett, A. Page, T. H. Palmer, H. Parry, W. Pate, C. C. Paterson, B. Paul, J. V. Peacock, F. Peasgood, W. M. D. Pell, W. O. Pepper, M. Petry, A. Pickersgill, R. C. Pierce, J. W. Piggott, D. E. Pledge, H. Pollock, E. L. Pope, A. H. Preece, H. F. Proctor, E. G. Pulford, A. P. Pyne, G. S. Ram, A. J. Ramsay, H. A. Ratcliff, W. R. Rawlings, R. H. Rawll, T. B. Reader, P. R. Rice, W. J. Rickets, E. S. Ritter, J. M. Robb, D. E. Roberts, B. A. Robinson, G. Robinson, J. H. Robinson, H. I. Rogers, P. Rosling, G. Ross, G. L. Rosser, S. Rudd, Dr. A. Russell, J. A. G. Russell, S. A. Russell, S. G. C. Russell, J. W. Ryde, H. S. Saunders, R. Savory, J. Sayers, J. E. Sayers, E. Seddon, W. Shead, J. E. Shepherd, H. W. Shilbach, J. F. Shipley, H. Sloog, J. F. Shoolbred, E. S. Shoults, J. W. Slorach, F. Smethurst, E. L. Smith, G. Smith, T. Smith, W. G. Smith, M. Solomon, J. E. Spagnoletti, A. L. Stanton, W. H. Steele, C. Stirling, H. Stokes, H. J. Stone, Rev. R. H. Streatfeild, Albert Stubbs, A. J. Stubbs, H. S. Styan, W. E. Styles, A. L. Tackley, W. J. Targett, E. E. Tasker, J. Taylor, J. E. Taylor, T. W. Terry, "The 25 Club," J. Thomas, L. Thomas, W. W. Thomas, F. A. Thompson, B. Thomsett, J. S. Thompson, C. H. R. Thorn, A. W. Tilbury, J. Toulmin, J. A. Troughton, F. Tyrrell, H. W. Umney, J. A. Vice, A. Vines, E. J. Wade, H. Walker, T. C. T. Walrond, C. E. Warner, J. W. Warr, F. Waters, E. C. Watson, H. J. G. Webb, W. White, J. Whitehead, H. K. Whitehorn, R. B. Whittick, S. L. Wong, W. J. H. Wood, J. H. Woolliscroft, J. E. Wright, W. R. Wynne, H. W. Young, W. Young, and C. W. Yung.

*Building Fund* :—M. Beales, J. D. Dallas, M. McA. Gillespie, J. S. Highfield, H. Hirst, Admiral Sir H. B. Jackson, E. A. Nash, and E. G. Pulford.

*Library* :—Messrs. E. Bennis & Co., Ltd., Messrs. Constable & Co., Ltd., The Diesel Engine Users' Association, The Director-General of Posts and Telegraphs (Calcutta), The Electrical Contractors' Association (Incorporated), The Editor of "Engineering," The Engineering Society, Sir Robert Hadfield, Bart., The Iron and Steel Institute, Mrs. W. P. Maycock, J. Millis, and The Ministry of Munitions (Editorial Committee).

The President announced the appointment of the Informal Meetings Committee and of the Wireless Sectional Meetings Committee (see *Institution Notes*, No. 11, p. 18, February 1919).

A paper by Mr. A. P. M. Fleming, O.B.E., Member, entitled "Planning a Works Research Organization" (see page 153) was read and discussed, and the meeting adjourned at 8.15 p.m.

## 622ND ORDINARY MEETING, 13 FEBRUARY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 23rd January, 1919, were taken as read, and were confirmed and signed.

A vote of condolence was passed with the family of the late Professor G. Carey Foster, LL.D., D.Sc., F.R.S., Past President and Honorary Member, the members standing in silence.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

A paper by Bt. Lieut.-Colonel W. A. J. O'Meara, C.M.G., Member, entitled "The Functions of the Engineer: His Education and Training" (see page 225), was read and discussed, and the meeting adjourned at 7.58 p.m.

## 623RD ORDINARY MEETING, 20 FEBRUARY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 13th February, 1919, were taken as read, and were confirmed and signed.

Messrs. H. C. Healey and F. Heppenstall were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

### ELECTIONS.

*Members.*

Higgs, Claude.
Nelson, Robert.
Thomson, George Hamilton.

*Associate Members.*

Abraham, Frederick Herman.
Anderson, Robert.
Andrews, Frank Walter.
Ault, Robert Herbert.
Bailey, Ralph Urwin.
Baldwin, William Leonard.
Bartlam, Ronald Ashley.
Bell, David Ernest.
Bowden, Edward, D.Sc.
Bury, Walter Edgar Latham.
Carnegie, Herbert Stirling.
Carpenter, Algernon Romaine.
Carter, William John.
Church, John William.
Clegg, John Flinton.
Colyer, James Frederick H.
Dutton, Harry.

*Associate Members*—continued.

Frankling, Albert Edward.
Frost, Harry George.
Goward, Albert.
Henderson, Alexander Robert.
Heslop, Henry Richard.
Hill, Norman MacLaren.
Hodges, John Percival.
Holley, William.
Hooper, Reginald Archibald A.
Horn, David James.
Howkins, George Pell.
John, William Charles F.
Jolley, Leonard Benjamin W.
Kenworthy, Arthur.
Lee, Alfred Fraser.
Lewton-Brain, Edwin.
Margerison, Charles Edgar.
Martin, Nathaniel, B.Sc. (Eng.).
Masaroon, Robert Gardner.
Mathieu, Gaston Adelin V.
Miller, Robert Shaw.
Morris, Edgar Reynolds.
Oxenham, William James.
Parker, William Alexander H.
Priestly, Percy.
Randall, Oswald Raymond, B.Sc.
Rodger, John Leitch, B.Sc.
Scott, George Smith.
Scragg, Frederick Thomas.
Sharp, Herbert Edward.
Shorter, William Henry.
Silcock, Arthur Howard.
Silva, Cuthbert Spencer.
Spiller, Leonard.
Twigg, John Henry.
Welbury, William.
Wilson, Robert Martill.
Wilson-Enderby, George Sidney.
Wotton, Walter John, M.B.E.
Yates, Alfred Tutnell.

*Associate.*

Keith, James.

*Graduates.*

Farrar, Romilly Rooth.
Hooper, William Percy.
Smith, James Stanley.

*Students.*

Ahmed, Mohamed Sinajuddin, B.Sc. (Eng.).
Allen, Norman Arthur.
Ayrton, Randle Ormrod.
Baggs, John.
Cameron, Charles.
Chadwick, Samuel.
Dickson, Robert.
Ellis, John Percy.
Filmer, Charles.
Ford, Lewis Hamilton.
Freeman, George Frederick.
Frost, Francis George.
Fry, Eric Rosewarne.
Georgeson, Hector Macdonald.
Gerry, Lionel Frederick.
Girling, James Lawrence.
Gough, Frederick.
Harding, John Ralph.
Hare, Leslie Wheaton.
Helguero, Joaquin Maria.
Hopkin, Cyril Walter Henry.
Hopwood, Robert Agar.
Isaac, Sydney Edward.
Jones, Albert Edward P.
Lazenby, Reginald.
Lyle, Alan Gordon.
Martin, Ernest.
Payne, Reginald William J.
Perkins, George Karl.
Plummer, Sidney Wallis.
Prosser, James Francis C.
Richardson, James Henry.
Robinson, Ernest Yeoman.
Smith, Dorothy (Miss).
Tait, Roderick Urquhart.
Walsh, Albert.
Warder, Stanley Bernard.
Watts, Arthur Edward W.
Whitfield, Charles Millard.
Wills, Frank.
Wright, Ernest Theodore.
Yapp, Spencer Raymond A.

TRANSFERS.

*Associate Member to Member.*

Baldwin, Francis George C.
Edmonds, Courtenay Harold W., Major, R.E.
Gavey, Arthur.
Green, Harry Hewlett R.
Schattner, Ernest B.
Shaw, Francis Blewett.

*Graduate to Associate Member.*

Feil, Walter Charles.
Hastings, Albert Anthony
Manly, Edward Harry.
Mistry, Nusserwanji Ruttonji, B.A., B.Sc.
Pask, Vincent Alexander.
Powell, Harry Hollins.
Rickets, William John.
Walker, Ernest.
Wybrow, Sidney George, Capt., R.A.F.

*Student to Associate Member.*

Charley, Reginald Morse, M.C.
Gresty, George.
Miller, John Ashbridge, Lieut., R.E.
Reid, Duncan Galt.
Stubbings, Charles Henry, B.Sc. (Eng.).
Thornton, Norman.
Wright, Cyril Victor C., B.Sc. (Eng.).
Wrigley, Philip.

*Student to Graduate.*

Bailey, Alfred.
Gripper, Laurence Albert.
Haigh, George.
Leeves, Arthur Henry.
Ram, Dewan Walaiti.
Reim, Ernest Philip.
Sadleir, John Rothwell.
Webb, Richard Jeffrey, Lieut., R.E.

The PRESIDENT announced that Mr. H. R. Constantine had been awarded the prize (see *Institution Notes*, No. 7, p. 25, June 1918) for a paper on the subject of "The Co-ordination of Research in Work and Laboratories."

Mr. G. L. Addenbrooke, Member, then delivered his first lecture on "Dielectrics in Electric Fields."

A vote of thanks to the lecturer, proposed by the President, was carried with acclamation, and the meeting adjourned at 7.20 p.m.

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# THE DETERMINATION OF THE EFFICIENCY OF THE TURBO-ALTERNATOR.

By S. F. Barclay, Ph.D., Associate Member, and S. P. Smith, D.Sc., Member.

(*Paper first received* 1 *November, and in final form* 19 *December*, 1918; *read before* The Institution 27 *February, before the* North-Western Centre 25 *February, before the* South Midland Centre 5 *March, before the* North-Eastern Centre 24 *March, and before the* North Midland Centre 8 *April*, 1919.)

Summary.

With the methods ordinarily employed of establishing the efficiency of the turbo-alternator, the stray loss that is present on load is either deduced by a substantially conventional method or is ignored altogether. As alternators for larger outputs are constructed, the stray loss becomes of greater importance and, indeed, may prove to be one of the factors that will limit the maximum size of unit that it is desirable to employ. A still more unsatisfactory feature of the existing methods is that it is becoming impracticable to apply them to the very large alternators now being constructed, on account of the difficulty of providing a driving motor of sufficient power. Further, with a driving motor, it is obviously impracticable to make any tests on site. It becomes increasingly important, therefore, to introduce a method of establishing the alternator efficiency which is based on the measurement of the actual losses on load.

The object of this paper is to show that the actual losses on load can be deduced conveniently and accurately from measurements of the cooling air flowing through the alternator. It is further shown, however, that although such methods are sound in principle, misleading results may be obtained unless certain precautions are taken in applying them.

## Introduction.

The efficiency of a turbo-alternator is usually expressed in terms of the rate of steam consumption in relation to the output of electrical energy, and therefore the purchaser has little direct economic interest in the accurate determination of the efficiency of the alternator. Nevertheless the matter is of considerable interest to the purchaser, since the efficiency of the alternator is an indication of the quality of the active materials employed and of the degree of excellence of the design. The manufacturer is more vitally concerned in the matter, for the reason that the accurate determination of the alternator efficiency is the only means of ascertaining the magnitude of the actual stray loss; for if the total loss on load can be found, the stray loss can be deduced when the other losses have been measured separately. With turbo-alternators of even moderate size the stray loss may be as high as five or six times the ohmic loss in the stator copper and, in the opinion of some authorities, this loss may prove to be one of the factors that will limit the output of electrical energy obtainable from a single unit. It will be seen, therefore, that if the efficiency on load can be determined accurately it will be one of the most important of the designer's informative tests.

The common practice in this country is to base the guarantees of the alternator efficiency on the summation of the various losses that can be measured separately, and either to ignore the stray loss altogether or to employ a substantially conventional method of determining it. Thus, some makers measure the windage and friction and the stator core loss (e.g. by driving the alternator with a calibrated motor) and calculate the copper losses (e.g. by deducing the full-load exciting current from open-circuit and short-circuit tests and taking the stator copper loss equal to the ohmic loss as for a direct current). The sum of the separate losses thus obtained is then assumed to represent the total losses in the alternator. The efficiency obtained in this way, however, is practically meaningless since the stray loss is entirely ignored. Other manufacturers make an allowance for the stray loss by assuming that it bears some definite relation to the stray loss present when the machine is run on short-circuit. In the conventional method adopted by the American Institute of Electrical Engineers, and used by some manufacturers in this country, the whole of the stray loss present on short-circuit is included when computing the conventional efficiency of polyphase machines (see Appendix II, Rule 458). That the nature and distri-

bution of the loss under the two conditions may be quite different, however, is shown by studying the heating in the two cases. When making short-circuit tests the authors have found in some cases great heating of the laminations at the ends of the stator core and considerable, although somewhat less, heating of the stator end-plates, whereas on full load the temperature of those parts was quite normal. For instance, in the case of a 5,000-kw. alternator at 3,000 r.p.m. embedded thermo-couples showed a temperature rise of 250 degrees F. at the ends of the stator core after running for an hour on short-circuit, although on full load the temperature rise of the same parts was only 60 degrees F. This phenomenon has not been fully investigated by the authors, but it is possibly due in part to a reverse flux between the stator core and the rotor steel end-bells which can only exist under short-circuit conditions. It will be seen, therefore, that when there is agreement between the value of the stray loss on load and on short-circuit it is partly accidental and is not to be expected in all cases. The investigations carried out by the authors confirm this reasoning, for although there is fairly close agreement between the two values in some cases, there is considerable disagreement in others, as is shown by the typical test results given in Table 7.

The efficiency can also be determined by running the alternator as an over-excited synchronous motor, but the kilovolt-amperes that have to be circulated limit the size of machine that can be dealt with in this way. Further, although the test can be made with full flux, a current lagging almost 90 degrees behind the electromotive force may give a value for the stray loss that is different from the actual loss on load. Also, the rotor copper loss with such a test is invariably too high, and to make the necessary correction entails a knowledge of the proper exciting current.

When two similar machines are available the Hopkinson test can be used, but the application of such a test to turbo-alternators is obviously very limited and is now rarely used.

It will be seen that at present there is not in common use any accurate method of determining the efficiency of the turbo-alternator, nor is there any standardized conventional method whatever in use in this country. It is an obvious and increasing necessity that a standardized method of establishing the efficiency should be adopted and, if possible, the method should not be one in which conventional values are assigned to one or more of the losses. Further, the method should preferably be one that can be applied at any time after the alternator has been erected on site.

For some time past the authors have been investigating the subject in conjunction with turbo-alternators made at the Sheffield works of Messrs. Vickers, Limited, and their investigations show that provided certain precautions are taken, the alternator efficiency can be conveniently and accurately determined under actual load conditions from measurements of the cooling air. From such measurements the separate losses can also be deduced—a matter of considerable importance when a driving motor is not available.

### Determination of the Loss in Turbo-alternators on Load from Measurements of the Cooling Air.

Modern turbo-alternators invariably have forced ventilation and, with the exception of the relatively small amount of heat dissipated from the external surface of the stator, all the losses except the bearing losses are carried off by the cooling air. Consequently the most obvious method of finding the losses on load is to ascertain, with regard to time, the heat energy that is being carried away by the ventilating air; for if the volume of air flowing through the machine in unit time, and the average increase in temperature that the air undergoes in absorbing the losses in the machine, are known, then the total losses on load can be calculated without difficulty. This method will hereinafter be referred to as the "air-heating" method. The principle involved in this method formed the subject of a paper on "The Testing of Electric Generators by Air Calorimetry," read before the Institution * in 1903 by Professor R. Threlfall, the machines in this case being totally enclosed in a specially constructed housing.

An alternative method which does not involve measuring the air volume, is to ascertain the increase in temperature of the cooling air caused by a loss of known magnitude in the alternator, and from the observed temperature rise of the air on load to deduce the total losses. This method will hereinafter be referred to as the "calibrated air-temperature" method.

In the determination of the losses in the alternator from the cooling air, the bearing losses are not included. Such an arrangement is not altogether illogical, since, when the turbine builder sub-lets the contract for the alternator, it is the custom for him to supply the alternator bearings and it is a simple matter for him to make the allowance for the bearing losses. These losses may be determined fairly accurately by measuring the volume and temperature rise of the lubricating oil and by making a suitable allowance for the heat dissipated in other ways. Since the bearing losses constitute but a small percentage of the whole, a fairly big error in determining them would have only a small effect on the result.

### Measurement of Air Volume and Temperature.

Air velocity can be measured in a variety of ways, and any of the following methods could be considered for our present purpose:—

(1) The Pitot tube.
(2) The Venturi tube.
(3) Electrical methods.
(4) The anemometer.

(1) *Pitot tube.*—The Pitot tube consists essentially of a dynamic tube placed in the line of air flow and a static tube with the plane of its orifice set at right angles to the line of air flow. The shape and size of the orifice of the dynamic tube have been found by careful experiment to be unimportant, but the size and position of the orifice of the static tube are most

* *Journal I.E.E.*, 1904, vol. 33, p. 28.

important.* Tubes conveying the two pressures, i.e. the dynamic and static heads, are connected to a differential fluid gauge. The difference of pressure that the gauge shows has been found to be proportional to the square of the air velocity over a very wide range. For the present purpose the average gauge readings are of the order of one-fifth of an inch of water, and for accurate work with such low pressures it is necessary to employ a special form of manometer with the tube inclined at a large angle to the vertical. The micro-manometer designed by Mr. B. J. B. Roberts † is very exact and has been employed by the authors in their investigations with excellent results. Another very accurate type of manometer is a tilting tube operated with a micrometer screw that is adjusted until the index bubble assumes the central position, and the difference of dynamic and static pressures is given by the micrometer reading.‡ Such instruments are

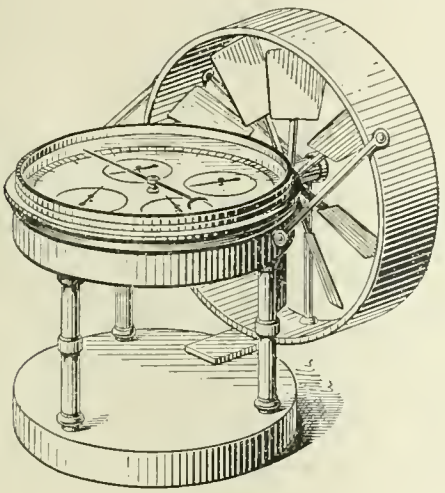

FIG. 1.—Type of anemometer used in tests.

hardly suitable for the present purpose, on account of the skill required in using them and the time required to take the readings. For example, Sir J. J. Thornycroft found that with the Roberts micro-manometer it may take five minutes or more for the index bubble to reach its final position.

The principal objection to the Pitot tube, however, for this work is that when making absolute measurements it is dependent for its accuracy on the air flow being in line with the dynamic tube and at right angles to the static tube—conditions that cannot exist when the air flow is variable in direction. To facilitate the accurate measurement of the velocity of the air leaving the alternator it is desirable to fit a temporary discharge trunk, as described below; but no matter what precautions of this kind be taken there is still some appreciable variation of the air velocity from point to point over the discharge outlet, indicating a non-streamline flow. With the air flow varying in direction from point to point in this way, any particular Pitot tube reading may not give accurately the average velocity at that part.

(2) *Venturi tube.*—The Venturi tube is a very exact instrument, but for its accuracy it is even more dependent than the Pitot tube on the flow of air being constant in direction, and it is therefore unsuitable for the present purpose.

(3) *Electrical methods.*—The electrical measurement of air velocity, based on the law that an electrically heated wire in a current of air cools at a rate that is dependent on the velocity of the air current, has been successfully carried out.* A wire of high electrical resistance-temperature coefficient, such as platinum, is employed, and either a constant voltage is maintained across it and the variation in resistance read, or the resistance is maintained at a constant value and the necessary variations of current are read. The air velocity is deduced from the readings on the basis of the law discovered by Dr. Kennelly and Messrs. Wright and Van Bylebelt,† that with unvarying wind velocity the linear forced convection from a thin wire increases as the square root of the air velocity. A hot-wire velocity indicator operating on this principle has recently been devised by Professor J. T. MacGregor-Morris, who kindly provided facilities for the authors to inspect the instrument. Four exactly similar wires of material having a high electrical resistance-temperature coefficient are arranged as a Wheatstone bridge. One pair of opposite arms of the bridge is exposed directly to the air current; the other pair is also in the air current, but is protected by being enclosed in thin-walled tubes of high thermal conductivity. This small bridge is attached to the end of a tube of convenient length and the leads are carried inside the tube to a portable battery and to a milliammeter or millivoltmeter. The difference between the cooling of the arms of the bridge that are exposed to the air current and the arms that are shielded from it is indicated on the ammeter or voltmeter, which can be calibrated to read the air velocity directly. The indicator attains a steady reading in a few seconds and, in the form described, it is suitable for measuring velocities up to about 2,000 feet per minute. Such an instrument should be satisfactory for measuring the air discharge from a turbo-alternator, particularly since the accuracy would be little affected by the air having a non-streamline flow, as must be the case to some extent. The authors have already made arrangements for testing the suitability of the instrument for the class of work in question.

(4) *Anemometer.*—The anemometer is usually considered to be somewhat unreliable, but for the purpose in view the authors have found that a well-made instrument when properly handled gave sufficiently accurate results. Further, on account of the air flow being variable in direction, the anemometer is probably better adapted to read the absolute value of the average velocity at a given point than are more exact instruments.

The two inherent defects of the anemometer are the effects of the friction and the inertia of the moving

* *Journal of the American Society of Mechanical Engineers*, 1912, vol. 34, p. 1341.
† *Proceedings of the Royal Society*, 1906, vol. 78A, p. 410.
‡ *Engineering*, 1912, vol. 94, p. 892, and *Ibid.*, 1913, vol. 96, p. 343.

* J. T. MORRIS: British Association, Section G, Dundee, 1912—see *Engineering*, 1912, vol. 94, p. 892.
† *Transactions of the American Institute of Electrical Engineers*, 1909, vol. 28, p. 303.

parts. The effect of friction on the reading is, however, slight when the velocity of the air is considerable. The velocity of the air discharge from a turbo-alternator is of the order of 2,000 feet per minute and, with an instrument of the kind used by the authors measuring about 2·6 inches over the tips of the vanes, the frictional effect is not more than 3 per cent of the vane-wheel speed, so that even an appreciable error in the correction for friction has only a negligible effect on the result. The other inherent defect of the anemometer—the effect of inertia—is of appreciable importance only when the air flow is variable. When a jet of air is directed on to the vanes there is a little delay before the vane wheel assumes the velocity corresponding to the air velocity; and, on the other hand, when the jet of air is removed the vane wheel continues to rotate for some time. The retardation period is decidedly longer than the acceleration period, with the result that when measuring a variable air velocity the anemometer tends to give too high a reading. This defect is of negligible importance for the object in view, since the air velocity does not vary at any given point.

TABLE 1.

*Machine No.* 7634.

| | | | | |
|---|---|---|---|---|
| V .. .. | 4,550 | 7,200 | 8,950 | 10,900 |
| $n$ .. .. | 1,500 | 2,400 | 3,000 | 3,600 |
| K .. .. | 3·033 | 3·000 | 2·983 | 3·028 |
| Variation from mean value of K .. | +0·73% | −0·37% | −0·93% | +0·56% |

The authors have checked the accuracy and consistency of the anemometer in several ways. When a fan delivers air to a given system of ducts, the volume of air discharged is a linear function of the speed of the fan*—that is, if V is the volume of air delivered in unit time, and $n$ is the speed of revolution of the fan, then $V = K n$, where K is a constant. Therefore, by running an alternator at various speeds and measuring the air volume in each case, the accuracy of the anemometer readings is established if they bear a constant ratio to the speed of rotation. The authors have found that the results obtained in this way are very satisfactory, as is shown in the typical case given in Table 1.

The accuracy of the anemometer readings was further checked by comparing a known loss in the alternator with the heat energy being carried away by the air. Such a proof is dependent on the accurate measurement of the average air temperature, and, in order to reduce possible error of this kind to a negligible extent, a large number of thermometers was employed. Typical results of such tests are given in Table 2, and the close agreement between the last columns will be noted.

In order to verify the consistency of the anemometer readings, two new instruments, calibrated at the National Physical Laboratory, and an instrument that had been in use for two years were mounted in succession in a given position at the discharge outlet of an alternator and were run for varying periods, during which the speed of the alternator and the load were maintained as constant as possible. The satisfactory results obtained are shown in Table 3. The instruments are necessarily delicate in construction and liable to damage by rough handling, so it is desirable that the accuracy should be tested in some such manner from time to time.

The anemometers used by the authors were supplied by Messrs. Negretti & Zambra and are of the type illustrated in Fig. 1. The makers guarantee the instruments not to vary more than 1 per cent over the range of air velocity for which they are suitable.

*Determination of average velocity of air.*—The first difficulty that the authors encountered in the measurement of the volume and temperature of the air was a consequence of the great variation in the velocity of the air at the discharge opening of the alternator, due to the essentially peculiar shape and disposition of the openings in the stator core and frame, and also

TABLE 2.

| Machine No. | Rotor Unexcited | | | | Rotor Excited | | | | Stator Core Loss + Excitation Loss in kw. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V | $T_i$ | $T_o$ | $P_u$* | V | $T_i$ | $T_o$ | $P_e$* | Calculated ($P_e - P_u$) | Measured by Driving Motor |
| 7,541 | 3,160 | 61·7 | 76·0 | 14·4 | 3,290 | 64·0 | 113·7 | 48·8 | 34·4 | 34·6 |
| 7,729 | 5,220 | 64·0 | 75·0 | 18·3 | 5,400 | 64·0 | 103·0 | 64·3 | 46·0 | 45·5 |
| 7,325 | 14,400 | 73·0 | 87·0 | 63·3 | 14,800 | 87·5 | 123·0 | 154·5 | 91·2 | 92·0 |

* $P_u$ and $P_e$ represent the losses heating the cooling air when the alternator is run unexcited and excited respectively, and are calculated from Equation (2) below.

* *Engineering*, 1915, vol. 99, p. 617.

TABLE 3.

| | | Calibrated Anemometer, No. 1 | Calibrated Anemometer, No. 2 | Test Anemometer (after two years' use) |
|---|---|---|---|---|
| Running for 1 minute | Dial reading .. .. | 1,316 | 1,296 | 1,325 |
| | Air velocity .. .. | 1,316 | 1,296 | 1,325 |
| | Variation from mean .. | 0·28% | 1·24% | 0·97% |
| Running for 5 minutes | Dial reading .. .. | 6,393 | 6,517 | 6,649 |
| | Air velocity .. .. | 1,318 | 1,304 | 1,329 |
| | Variation from mean .. | 0·08% | 0·99% | 0·91% |
| Running for 15 minutes | Dial reading .. .. | 19,804 | 19,504 | 20,020 |
| | Air velocity .. .. | 1,320 | 1,300 | 1,335 |
| | Variation from mean .. | 0·15% | 1·37% | 1·29% |
| Running for 60 minutes | Dial reading .. .. | 79,563 | 79,027 | 80,469 |
| | Air velocity .. .. | 1,326 | 1,317 | 1,341 |
| | Variation from mean .. | 0·15% | 0·83% | 0·98% |

of the rotation of the rotor tending to cause the air to discharge obliquely instead of vertically.

In order to investigate the nature of the air flow, a Pitot tube was mounted on suitable gear and was slowly traversed across the discharge opening. The type of Pitot tube used is shown in Fig. 2, and the manometer used in conjunction with it was of the Roberts pattern with xylol for a fluid (specific gravity, 0·856). Before taking each reading the inclination of the Pitot tube was varied until a maximum displacement in the manometer was obtained. By taking readings in this way at frequent intervals, the variation in the direction and velocity of the air over the discharge

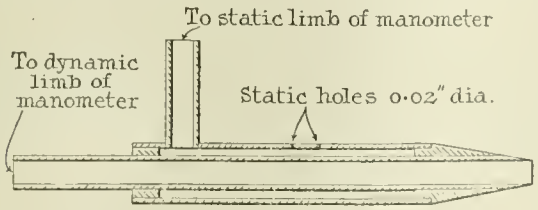


FIG. 2.—Pitot tube.

opening was ascertained fairly accurately. It was found that the air was eddying violently and that there was actually a reverse flow in some places. With such a variable air flow, the accurate measurement of the volume and average temperature is a matter of the greatest difficulty, and most probably the results obtained under such conditions would be quite misleading. With the object of equalizing the air flow, a temporary discharge trunk of the kind shown in Fig. 3 was fitted and the air velocity was again measured by traversing the Pitot tube across the discharge opening. The improved result obtained with the trunk is shown by curve B in Fig. 4. To equalize further the air velocity, close-mesh expanded-metal baffle plates were fitted in the trunk as shown in Fig. 3 and the improvement obtained is shown by curve A in Fig. 4. It will be seen that although there is still some variation, yet if the anemometer readings are taken at fairly frequent intervals the average velocity can be found with a

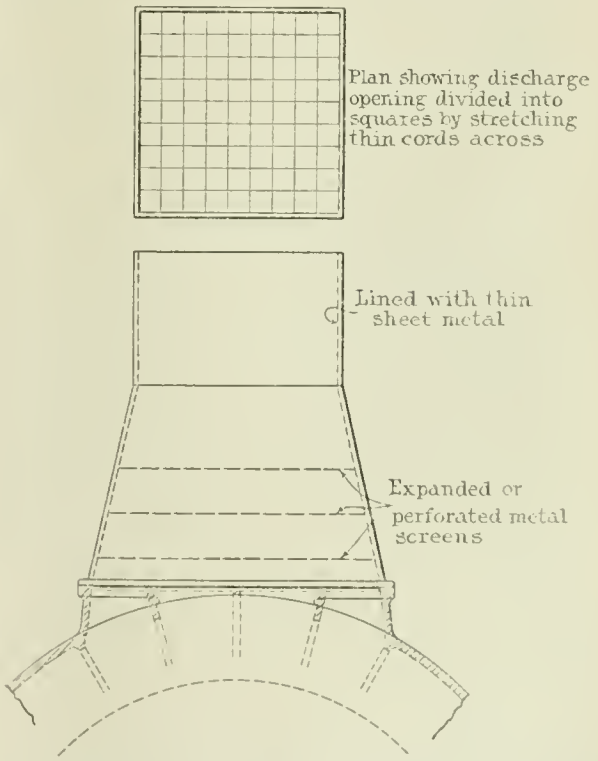
Plan showing discharge opening divided into squares by stretching thin cords across
Lined with thin sheet metal
Expanded or perforated metal screens

FIG. 3.—Temporary discharge trunk to facilitate the accurate measurement of the air volume and temperature.

sufficient degree of accuracy. The resistance of the expanded metal baffles to the flow of air was found to have no appreciable effect on the temperature of the alternator. Of course, if there were any effect of this

kind it would not affect the accuracy of the determination of the losses in the alternator, for any restriction of the flow of air would only cause a corresponding increase in temperature; but the matter would be important in so far as the efficiency could not be measured during the heating test—which is desirable from the point of view of saving time and also, if running on an artificial load, expense.

For the accurate measurement of the air volume it is desirable that the discharge opening should be divided into squares, not much larger than the overall diameter of the anemometer, by stretching thin cords across the trunk as shown in Fig. 3, and an anemometer reading should be taken over each square. For small and medium-size machines the squares could conveniently be made with a length of side of 4 inches, but for very large machines the size might be increased

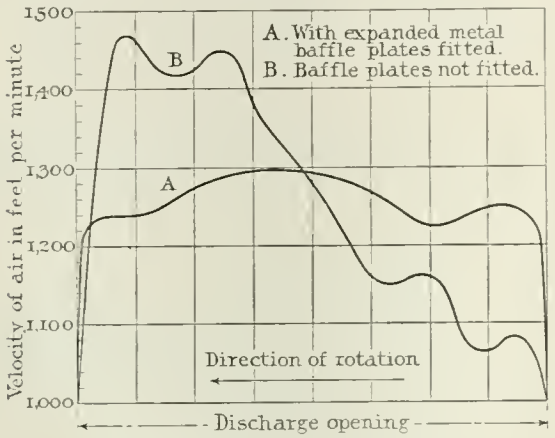


FIG. 4.—Curves plotted from Pitot tube readings taken at opening of temporary discharge trunk.

somewhat to avoid taking an unnecessarily large number of readings. A certain error is introduced into the readings by the delay in starting and stopping the anemometer, and also as a consequence of the manipulation of the catch that throws the recording dials in and out of gear, interfering locally with the air flow. These difficulties can readily be overcome by moving the instrument rapidly from square to square without stopping it, and the average value of the air velocity is found by dividing the total reading by the number of squares. The authors have found a slight but appreciable effect in adopting this safeguard. It is desirable to run the anemometer for an appreciable period over each square—15 seconds being the minimum desirable time and a longer period up to one minute being preferable when circumstances permit.

*Determination of average temperature of air.*—The average temperature of the air can be found with sufficient accuracy by using one thermometer for each square and taking the average of the readings. The thermometers can conveniently be attached to the cords in a horizontal position. The authors have tried the experiment of using several thermometers in each square, but they find that the result is not appreciably different from that obtained by using one for each square. The determination of the average temperature of the inlet air presents no difficulty, but it should be verified that there is no external source of heat, such as a steam pipe, near the thermometers. When an air filter is used in conjunction with the alternator, the inlet temperature has to be read between the filter and the alternator, and it is particularly necessary to do so when the filter is of the wet type.

The average temperature of the air at the inlets and outlets can also be determined very accurately by measuring the change in resistance of a coil of wire, of which the electrical resistance-temperature coefficient is known, mounted in the air flow. The authors have found very close agreement between the results obtained in this way and those obtained by thermometer measurement, but for general work the thermometer is obviously more convenient.

It is not infrequently the custom with large alternators to discharge the ventilating air from the bottom of the stator and lead it away in ducts from the engine room. In such cases it is quite convenient to provide at the top of the alternator a discharge opening that can be used for making the air-volume and air-temperature measurements. Whilst the tests are being made, the lower discharge opening is temporarily closed, and for normal running the upper opening is closed with a plate. By standardizing the size of discharge opening only a few temporary discharge trunks are necessary for a wide range of sizes of alternators.

*It will be seen that the precautions to be taken in the measurement of the air volume and temperature are simple, but without such precautions the authors have found that quite misleading results may be obtained.*

## METHOD 1.

### THE DETERMINATION OF THE LOSSES ON LOAD BY THE "AIR-HEATING" METHOD.

Having seen that it is quite practicable to measure the volume and temperature rise of the air with sufficient accuracy, the method of calculating the losses from the volume and temperature rise of the air will now be described. In making the following calculations the value of 0·0711 lb. is taken for the weight of a cubic foot and 0·242 for the specific heat of dry air at the assumed temperature of 100° F. and at an atmospheric pressure equal to 29·92 inches of mercury. The mechanical equivalent of heat is taken to be 778 foot-pounds per therm.

Let $V$ = volume of air leaving the alternator discharge in cubic feet per minute,
$T_i$ = average temperature of the air at the inlets,
$T_o$ = average temperature of the air at the alternator discharge.

The heat energy being carried away by the air is then

$$P = V \times 0{\cdot}0711 \times 0{\cdot}242 \times (T_o - T_i) \times 778 \text{ foot-pounds per minute,}$$

$$= \frac{V \times 0{\cdot}0711 \times 0{\cdot}242 \times (T_o - T_i) \times 778 \times 746}{33{,}000 \times 1{,}000} \text{ kilowatts,}$$

$$= \frac{V\,(T_o - T_i)}{3{,}305} \text{ kilowatts} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $T_i$ and $T_o$ are in degrees Fahrenheit.

The various corrections that may have to be made to the above formula are dealt with in Appendix I. It is there shown that, for commercial testing, corrections need be made only in the event of the air temperature or barometric pressure differing appreciably from the conditions assumed and in respect of the heat energy that is dissipated from the stator frame. The correction curves given in the appendix may be used with formula (1), or this formula may be amended to include the corrections as follows :—

$$P=\frac{V\,(T_o-T_i)}{3{,}305}\times\frac{H}{29{\cdot}92}\times\frac{460+100}{460+T_o}\times\frac{100}{98{\cdot}5},$$
$$=\frac{V\,H\,(T_o-T_i)}{174\,(460+T_o)}\text{ kilowatts}\quad .\quad .\quad .\quad .\quad .\quad (2)$$

where $T_i$ and $T_o$ are in degrees Fahrenheit.

If $T_o$ and $T_i$ are in degrees Centigrade

$$P=\frac{V\,H\,(T_o-T_i)}{174\,(273+T_o)}\text{ kilowatts}\quad .\quad .\quad .\quad (2A)$$

### Method 2.

### The Determination of the Losses on Load by the "Calibrated Air-temperature" Method.

Various methods have been suggested for calibrating the temperature rise of the air in terms of the loss in the alternator. The following method was adopted by the authors as being convenient and independent of the use of any quantities that cannot be measured directly.

When the alternator coupled to a driving motor is being run at the works, the stator core loss with various values of the exciting current can be measured —a test that it is always desirable for the maker to carry out for his own information. When the machine is being tested on site, the temperature rise of the cooling air is measured (1) on open circuit with the rotor unexcited, (2) on open circuit with the rotor excited to a known value, (3) with the alternator on load.

Let $t_e$ denote the temperature rise of the cooling air in test (2) with the rotor excited,
$P_c$ the rotor copper loss,
and $P_i$ the stator core loss corresponding to this excitation (the value of $P_i$ is given by the core-loss curve taken at the works).

Then, if $t_u$ denotes the temperature rise of the cooling air in test (1) with the rotor unexcited, it follows that the difference $t_e-t_u$ in the rise in temperature of the cooling air is caused by the known loss $P_i+P_c$ kilowatts. The loss in the alternator necessary to cause the temperature of the ventilating air to increase one degree is then

$$\Delta P=\frac{P_i+P_c}{t_e-t_u}\text{ kilowatts.}$$

The quantity $\Delta P$ thus represents the calibration of the temperature rise of the cooling air of the machine in question.

If now $t_l$ denotes the temperature rise of the cooling air in test (3) when the alternator is on load, it follows that the load loss will be—

$$P=\frac{P_i+P_c}{t_e-t_u}t_l=\Delta P\times t_l\text{ kilowatts}\quad .\quad .\quad .\quad (3)$$

The formula holds good, of course, for either the Fahrenheit or the Centigrade thermometer.

The accuracy of the "calibrated air-temperature" method depends mainly upon the weight of air flowing through the machine remaining constant whilst the heating tests are being made. The effect of losses in the alternator is of course to heat the air and cause it to expand and so increase the volume for a given weight. The opposition to the flow of an increased volume of air will depend on the position of the parts where there is the greatest restriction to the air flow with respect to the position of the parts where the heating occurs. For instance, with a radially-ventilated stator the resistance encountered by the air passing from the fan chambers to the gap and from the gap to the radial ducts constitutes the principal restriction to the air flow; consequently, additional heating in the stator core would affect the weight of air flowing through the machine very little, whereas additional heating in the fan chambers and rotor would have appreciable effect. With large machines it may be found that the calibration loss cannot conveniently be made greater than about one-half the total load losses even when running considerably over-excited. On load, the loss in the body of the core will be considerably less than during an over-excited calibration test and the greater loss will be in the rotor, the stator copper, and the stator teeth. This alteration in the distribution of the loss, and the greater magnitude of it, will cause the air to increase in temperature and expand before it enters the stator ducts, and so the volume of air flowing through the machine cannot increase in quite the same proportion as the increase in the absolute temperature of the air—as must be the case for the air weight to remain constant. The effect of this reduction in the weight of air flowing through the machine under load is to make the calibration figure $\Delta P$ slightly high with respect to actual load conditions or, alternatively, the temperature rise $t_l$ on load slightly high with respect to the calibration conditions; in consequence of which the load losses given by this method are somewhat too large. The extreme magnitude that it would be possible for this error to have would exist if the air volume on load were the same as during the calibration test; in this case the reduction in the weight of air would cause an error of about 4·4 per cent (this figure is arrived at on the assumed probable conditions of the air entering at 45° F., the windage loss causing a rise of 15 degrees F., the calibration loss a rise of 25 degrees F., and the load loss a rise of 50 degrees F.). The actual error, however, will be less than 4·4 per cent, since all the additional air-heating on load, compared with the heating during calibration, does not take place before the air flows through the points of restriction, and the authors have estimated that even in radially-ventilated machines the losses given by this method are only

2 to 3 per cent too high. This estimate is confirmed by tests (cf. Table 6). A general correction cannot be made in respect of this error, since it will be influenced by the system of ventilation apart from the different distribution and magnitude of the losses during calibration and on load. Also, for the latter reason, the slight error due to the difference in the dissipation of heat from the stator under the two conditions cannot be corrected by a constant multiplier, as is possible with the "air-heating" method. In the absence of accurate information it can be assumed that due to these causes the losses obtained by the "calibrated air-temperature" method are $2\frac{1}{2}$ per cent too high.

## Tests.

Typical results obtained by the "air-heating" and "calibrated air-temperature" methods are given in Tables 4 and 5. A comparison of the losses so obtained

Table 4.

*Determination of Load Loss by the "Air-heating" Method.*

| Machine No. | Air Volume in Cub. Ft. per Min. | Air Temp. in °F. at | | Load Loss in kw. (from Equation 2) |
|---|---|---|---|---|
| | | Inlet $T_i$ | Outlet $T_o$ | |
| 5,862 | 16,800 | 45·0 | 116·6 | 352 |
| 7,001 | 21,330 | 53·0 | 103·9 | 327 |
| 7,541 | 3,300 | 66·2 | 114·0 | 46 |

with the "summation of losses" method as adopted by the American Institute of Electrical Engineers, and with this method when an allowance for stray loss is excluded, is given in Table 6.

## General Conclusions.

*"Air-heating" method.*—These investigations have led the authors to the opinion that the "air-heating" method may quite well be adopted for the determination of the turbo-alternator efficiency for commercial purposes, with advantage to the purchaser and the manufacturer. By taking the prescribed precautions when measuring the air volume and temperature, the losses on load can be determined quite as accurately as is required and probably more accurately than in any other way. From the manufacturer's point of view a great advantage of the method is that a driving

Table 6.

*Comparison of Results obtained by Four Different Methods.*

| Machine No. | Methods based on Cooling Air | | Methods based on "Summation of Losses" | |
|---|---|---|---|---|
| | "Air-heating" Method | "Calibrated Air-temperature" Method | A.I.E.E. Method | Stray Loss Ignored |
| 5,862 | 352 | 362 | 336 | 211 |
| 7,001 | 327 | 338 | 315 | 255 |
| 7,541 | 46 | 47 | 52·5 | 42·8 |

Table 7.

*Comparison of Stray Loss on Load with Stray Loss on Short-circuit.*

| Machine No. | Stray Loss on Load (determined by "Air-heating" Method) | Stray Loss on Short-circuit (as determined in A.I.E.E. Conventional Method) |
|---|---|---|
| 5,862 | 141 | 125 |
| 7,001 | 72 | 60 |
| 7,541 | 3·2 | 9·7 |

motor is not required—an item of importance when dealing with alternators of large output. Also, when on account of transportation difficulties the stator has to be built on site, in addition to measuring the total losses on load the method could also be employed to measure the separate losses with ease and accuracy.

Table 5.

*Determination of Load Loss by "Calibrated Air-temperature" Method.*

| Machine No. | Known Loss $P_i+P_c$ | Air Temperature-rise with Rotor | | Air Rise due to $P_i+P_c$ :— $t_e-t_u$ | $\Delta P=\frac{P_i+P_c}{t_e-t_u}$ | Air Rise on Load $t_l$ | Load Loss (from Equation 3) $\Delta P . t_l$ |
|---|---|---|---|---|---|---|---|
| | | Unexcited $t_u$ | Excited $t_e$ | | | | |
| 5,862 | 167·5 | 15·1 | 48·3 | 33·2 | 5·05 | 71·6 | 362 |
| 7,001 | 195·5 | 20·4 | 51·2 | 30·8 | 6·35 | 53·4 | 338 |
| 7,541 | 34·6 | 14·3 | 49·6 | 35·3 | 0·98 | 47·8 | 47 |

The method is independent of tests made at the works, and in the event of dispute a check test could be made at any time. The ease with which the test is applied would enable periodic readings of the losses to be taken, and useful information concerning the variation of efficiency (if any) with age could be obtained. Moreover, the measurement of the air volume that would be involved would be of value in indicating accurately if any restriction to the air flow was arising due either to the ducts in the alternator becoming choked with foreign matter or to increased resistance in the filter.

" *Calibrated air-temperature* " *method.*—This method has the one advantage, compared with the " air-heating " method, that the air volume has not to be measured, but on the other hand it has certain disadvantages. The efficiency cannot be determined solely by tests on site, and once the alternator has been despatched from the works a check test in the case of dispute cannot be made.

In addition to any error due to the weight of air flowing through the machine being somewhat less on load than during calibration as already discussed, a further possible cause of error is in the determination of the stator core loss, on which the result is based. It is usually necessary to employ reduction gearing or a belt drive between the driving motor and the alternator, and in such cases there is uncertainty as to the transmission losses. The authors have had the opportunity of comparing the losses in two sets of modern double-helical gears when transmitting power and they found an appreciable difference between the results. The loss with a belt drive when transmitting power at a high speed is liable to vary and is difficult to determine accurately.

When a driving motor is not available, as may be the case with large machines or when the stator has to be built on site, the core loss can be ascertained only by the application of some such method as the sudden cutting off of the steam supply and measuring the difference in retardation caused by the core loss. From these measurements and a calculation of the inertia of the revolving mass, the core loss can be deduced. Apart, however, from the difficulty of ascertaining the losses in this way, an accurate result is not to be expected therefrom.

*Existing methods.* — The " summation of losses " methods in present use which ignore the stray loss have little value except that in the absence of any standardized logical method they serve to prevent disputes between the contracting parties when the turbine builder sub-lets the contract for the alternator. With regard to the special form of the " summation of losses " method put forward by the American Institute of Electrical Engineers, it has already been noted that the total losses obtained in this way may not in some cases differ sufficiently from the true loss to affect seriously the value of the efficiency deduced therefrom (cf. Table 6) ; but the conventional allowance made for the stray loss may differ appreciably from the actual value (cf. Table 7). Apart from the inaccuracy of these methods in principle, there is the possibility of error in measuring the various losses. Thus, to ascertain the excitation loss, the exciting current has to be calculated, e.g. from the open-circuit and short-circuit curves. Reference has already been made to the possible inaccuracies in measuring the core loss with a driving motor, and still more so when a driving motor is not available.

An extract from the Rules of the American Institute of Electrical Engineers relevant to the determination of turbo-alternator efficiency is given in Appendix 2.

It is unnecessary to deal with the various unsatisfactory methods of determining efficiency that are in use, with which dependence in a lesser or greater degree is placed on guess-work.

In conclusion, the authors beg to express their obligation to Mr. Douglas Vickers and Mr. W. Clark, directors of Messrs. Vickers, Ltd., for permission to carry out the experimental investigations referred to in this paper and to publish the results ; also to Mr. H. P. Hayhurst and his testing staff for the care that they have taken in carrying out the tests.

## APPENDIX I.

### Corrections for " Air-heating " Method.

*Correction* 1. *Effect of temperature on air density.*— At a given atmospheric pressure, the weight per cubic foot of air varies in inverse proportion to the absolute temperature. In making the calculations given in formula (1) the temperature of the air at the discharge is assumed to be 100° F., and a cubic foot of dry air at that temperature with the standard atmospheric pressure weighs 0·0711 lb. per cubic foot. The actual

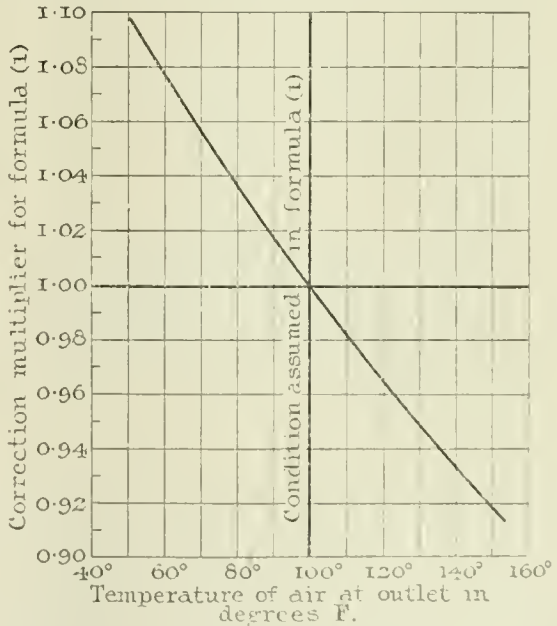


Fig. 5.—Correction in respect of variation of air density with temperature for use with formula (1). (This correction is allowed for in formulæ (2) and (2A).)

weight of air passing through the machine per minute when the outlet temperature is $T_o$° Fahrenheit is given by

$$\frac{(460+100)}{(460+T_o)} \times 0{\cdot}0711 \times V \text{ lb.}$$

This expression is for dry air and standard barometer.

If the air temperature should differ appreciably from the value assumed, as it may, an important error would arise, as will be seen from the curve given in Fig. 5. The formulæ in their final form, (2) and (2A), have the correction included, but, if formula (1) is used, the necessary correction is to be read from the curve corresponding to the temperature of the outlet air.

*Correction 2. Effect of atmospheric pressure on air density.*—For a given temperature, the weight of air is directly proportional to the atmospheric pressure. In this country the barometer at the sea level seldom

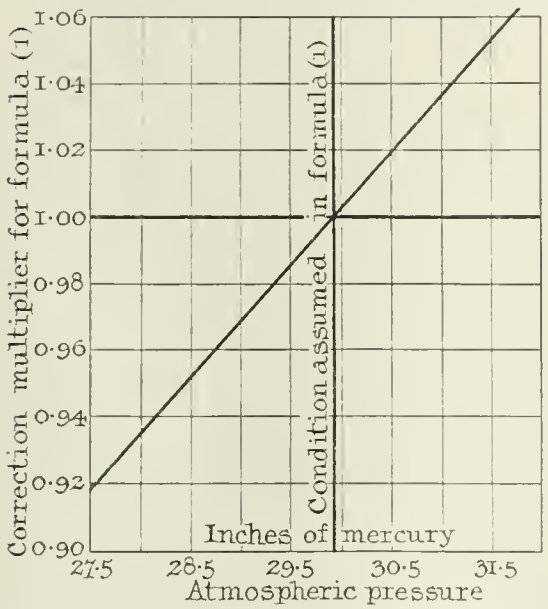


FIG. 6.—Correction in respect of variation of air density with atmospheric pressure, for use with formula (1). (This correction is allowed for in formulæ (2) and (2A).)

reads higher than 30·5 inches and seldom lower than 28·5 inches, but a pressure as low as 27·332 inches has been recorded in Scotland and as high as 31·62 inches in Siberia.* Allowing for some power stations being at a considerable height above sea level, an appreciable variation from the standard barometric pressure of 29·92 inches may well be experienced. The weight of air per minute passing through the machine, if dry and at the temperature of 100° F., is found from the expression

$$\frac{H}{29{\cdot}92} \times 0{\cdot}0711 \times V \text{ lb.},$$

where H denotes the atmospheric pressure in inches of mercury. The formulæ in their final form, (2) and

* F. W. HENKEL: "Weather Science," p. 65.

(2A), have the correction included, but, if formula (1) is used, the necessary correction is to be read from the curve given in Fig. 6 corresponding to the barometer reading at the time the test is made.

*Correction 3. Effect of humidity on air density and specific heat.*—At a given pressure and temperature, the weight of a cubic foot of air varies a little according to the degree of humidity, in consequence of water vapour being lighter than air. On the other hand, water vapour has a higher specific heat than air, hence the effect on humidity is to increase slightly the specific heat of the air, so that in considering the correction the combined effect has to be ascertained.

The effect of humidity on the air density will be dealt with first. The density of water vapour varies considerably with the temperature, as is shown in Fig. 7. The pressure of water vapour at different temperatures is shown in Fig. 8. From these curves

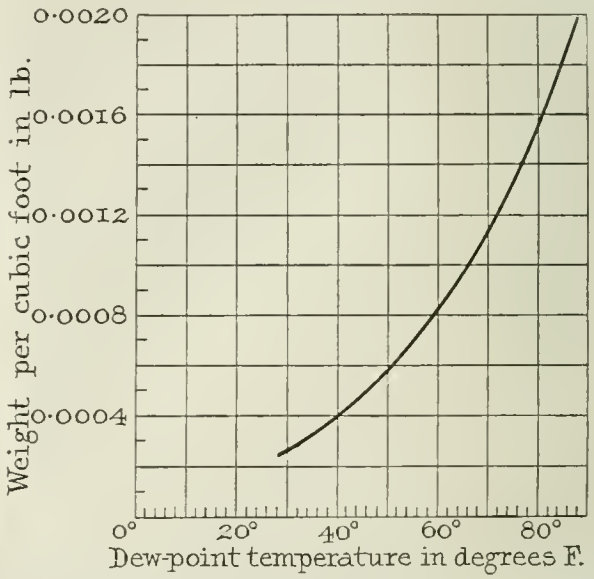


FIG. 7.—Curve showing the weight of aqueous vapour at various temperatures (from values obtained by Regnault).

the weight of unsaturated moist air at a given temperature and pressure can be calculated. From Dalton's Law of Partial Pressures, it is known that the total pressure exerted by a mixture of two gases in a vessel is equal to the sum of the pressures that would be exerted if each filled the vessel alone. The temperature at which the air would be saturated, i.e. the dew-point, having been ascertained, the pressure of the aqueous vapour is found from Fig. 8. This pressure is deducted from the atmospheric pressure, and the weight of dry air contained in a cubic foot of the moist air is found by multiplying the weight of a cubic foot of dry air by this value and dividing by the atmospheric pressure. The weight of the water vapour contained in a cubic foot of the moist air is ascertained from the curve in Fig. 7 corresponding to the dew-point temperature. The sum of the two gives the weight of a cubic foot of

the moist air. The expression for the weight of a cubic foot of moist air is then

$$\frac{0{\cdot}0711\,(H-H_v)}{H}+W_v \text{ lb.},$$

where H = atmospheric pressure in inches of mercury,
$H_v$ = vapour pressure obtained from Fig. 8, corresponding to the temperature at which the moist air would be saturated,
$W_v$ = weight of a cubic foot of water vapour obtained from Fig. 7, corresponding to the temperature at which the moist air would be saturated.

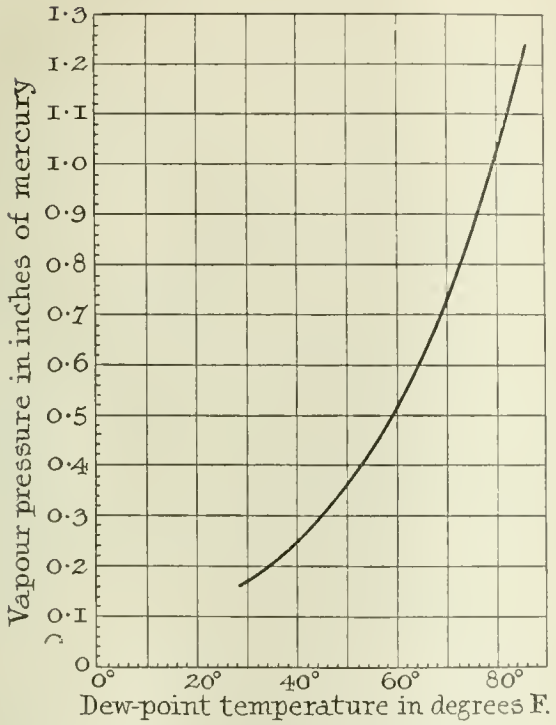


FIG. 8.—Curve showing the pressure of the water vapour in saturated air at various temperatures (from values obtained by Regnault).

The effect of humidity on the specific heat will now be considered. The specific heat of moist air is expressed by

$$\frac{S_a W_a+S_v W_v}{W_a+W_v},$$

where $S_a$ = specific heat of the air,
$S_v$ = specific heat of the aqueous vapour,
$W_a$ = weight of the dry air contained in a cubic foot of the mixture,
$W_v$ = weight of the aqueous vapour contained in a cubic foot of the mixture.

The weight of a cubic foot of air at the standard barometric pressure is given in Fig. 9, and the weight of a cubic foot of aqueous vapour is given in Fig. 7. The specific heat of air is to be taken at the constant value of 0·242—the variation with temperature will be dealt with separately. The specific heat of water vapour may be assumed to have the constant value of 0·475—the variation with changes of temperature is slight, and can be ignored when applying the above formula.

With the worst conditions that are likely to arise in practice, either of these two effects *per se* might affect the value of the losses in the alternator, as determined by the "air-heating" method, by as much as about 3 per cent. As already explained, however, the one effect tends to cancel the other and the net result is as shown in Fig. 10. It will be seen that with the worst case that is likely to arise, the correction is sufficiently small to warrant it being neglected for commercial work. The final formulæ, (2) and (2A), for determining the losses by the "air-heating" method therefore do not include any correction for the effect of humidity.

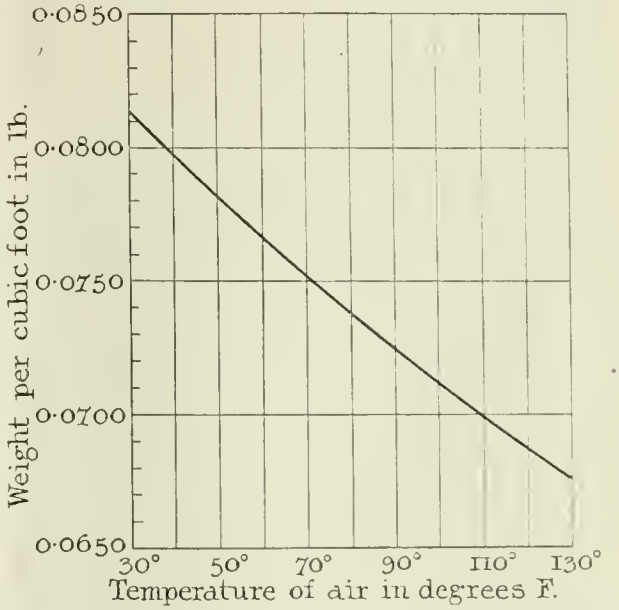


FIG. 9.—Curve showing the weight of a cubic foot of dry air at various temperatures. (Barometer: 29·92 inches of mercury.)

*Correction* 4. *Effect of temperature on specific heat.*—A very careful investigation made by Mr. W. F. G. Swann * showed that the specific heat of air varies very little with increase in temperature. The result of Mr. Swann's investigation is given in Fig. 11, from which it will be seen that between 60° F. and 100° F. the specific heat increases by only 0·145 per cent. If the temperature of the air leaving the alternator were as high as 140° F. instead of the assumed condition of 100° F., the error due to the change in the specific heat would be little more than one-fourth of ·1 per cent. It is therefore quite unnecessary to make a correction in respect of the variation of the specific heat.

*Correction* 5. *Effect of heat dissipated from the stator frame.*—To ascertain the heat energy that is dissipated from the external surface of a turbo-alternator, a

* *Philosophical Transactions of the Royal Society*, vol. 210A, p. 230.

careful test was made with a 5,000-kw. 3,000-r.p.m. machine. With the rotor at rest and the air inlets and outlets closed, a direct current was passed through

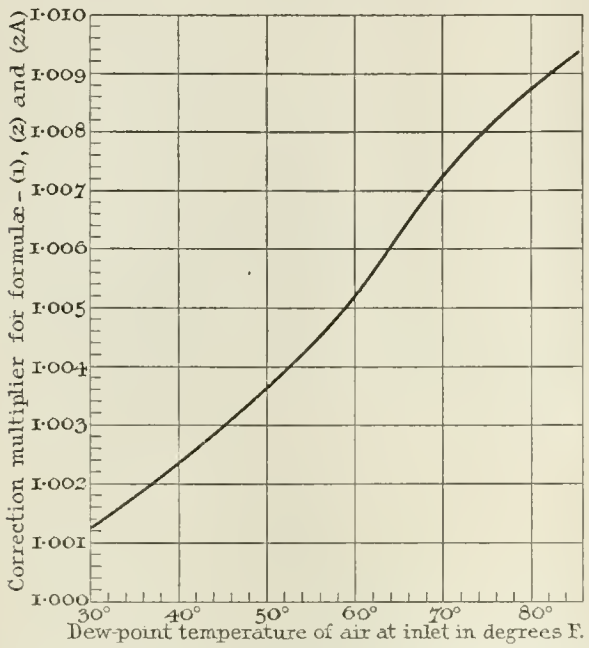


FIG. 10.—Correction in respect of variation of air density and specific heat with humidity. (This correction may be ignored for commercial work, and is not taken into account in any of the formulæ.)

the stator winding. When the temperature rise of the external surface reached a steady value it was found that the heat energy being dissipated was

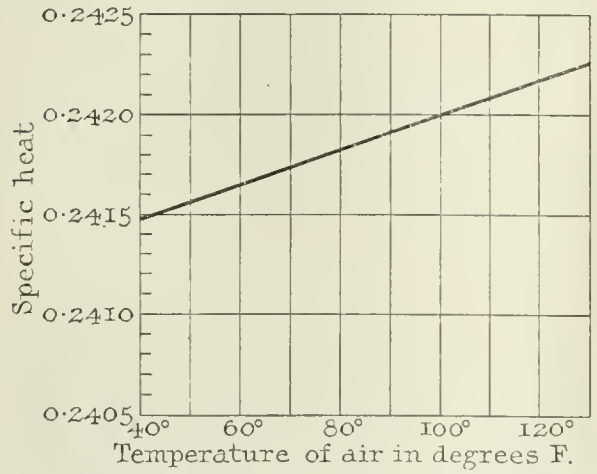


FIG. 11.—Curve showing the variation of the specific heat of dry air with variation of temperature. (From values determined by Mr. W. F. G. Swann.)

0·006 watt per inch of surface per degree rise (Fahrenheit). To neglect a correction for radiation would give an error in the average case of about 1½ per cent on the losses determined by the "air-heating" method. Although this error is small, it is practically constant and the necessary correction is easily made. The formulæ in their final form, (2) and (2A), include this correction.

*Minor causes of error.*—There will be a certain tendency for the air entering the alternator to absorb heat conducted through the shaft from the bearings. Further, the small loss in the slip-rings will not be measured, since they are exterior to the alternator. It is obvious that the errors introduced as a consequence of these minor matters will be infinitesimal in degree, particularly as the error introduced by the tendency for heat to flow from the bearings into the alternator is off-set by the slip-ring loss that is not measured.

## APPENDIX II.

### Extract from the Rules of the American Institute of Electrical Engineers.*

422. In the case of machinery two efficiencies are recognized, conventional efficiency and directly measured efficiency. Unless otherwise specified, the conventional efficiency is to be employed.

423. Conventional efficiency of machinery is the ratio of the output to the sum of the output and losses; or of the input minus the losses to the input; when, in either case, conventional values are assigned to one or more of these losses. The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practically indeterminable, and must, in many cases, either be approximated by an approved method of test, or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "conventional efficiency."

441. Losses to be taken into account in synchronous motors and generators.

Core losses—see Rule 452.

$I^2 R$ loss in all windings, based upon rated k.v.a. and power factor.

Stray load losses.—In approximating these losses, the method described in Rule 458 shall be employed.

Friction of bearings and windage.

452. *Core loss.*—The machine is driven from an independent motor, the difference in output of which is determined when the machine is unexcited and when it is excited to give the terminal voltage corrected for the resistance drop only. (This rule has been paraphrased.)

458. *Stray load losses in synchronous generators and motors.*—These include iron losses, and eddy-current losses in the copper, due to fluxes varying with load and also to saturation. Stray load-losses are to be determined by operating the machine on short-circuit and at rated-load current. This, after deducting the windage and friction and $I^2 R$ loss, gives the stray load loss for polyphase generators and motors. These losses in single-phase machines are large; but the Institute is not yet prepared to specify a method for measuring them.

* *Transactions of the American Institute of Electrical Engineers*, 1916, vol. 35, p. 1559.

## Discussion before The Institution, 27 February, 1919.

**Professor G. W. O. Howe**: I think it is a very good sign that a paper on this important subject has been written by collaboration between a representative of one of the largest electrical manufacturing firms and a representative of one of our technical colleges. It shows, on the one hand, that our manufacturers are fully alive to the importance of scientific investigation, and on the other hand it is a guarantee that our students are not being raised in an atmosphere of prehistoric design. The stray losses in alternators are very serious and puzzling, and it is surprising how little has been published which throws any light on the actual causes of these very large undetermined losses. The main cause of these stray losses is, I feel sure, that the armature reaction causes the field to be distorted and to take paths otherwise than parallel to the laminations, so that some of the flux is driven across the laminations and not along their length. This would cause very large eddy currents to be set up in the laminations. I think that this is probably the cause of the larger part of these losses. At the time of Professor Threlfall's work, everyone felt that his method was very cumbersome, and, although of scientific interest at the time, it was of very little practical importance. I think no one foresaw then that in a few years alternators would be so designed as to lend themselves naturally to this method of determining the efficiency, and I feel sure that the numerical results given in the present paper prove the convenience and the accuracy of the method. I have little doubt, however, that the convenience of the method will, in time, be greatly increased by the introduction of improved methods of measuring air delivery and the increase in temperature of the air. One point which does not appear to have been brought out very clearly in the paper is the necessity for running the machine until the temperature throughout is steady. Unless that is so, it seems to me that some of the heat generated—and I should imagine an appreciable part—is absorbed by the iron and copper which has not yet reached its final temperature. I wish the authors would give a little more information on this point. I presume that in some of these large turbo-alternators the thermal time-constant of the machine is considerable, and it will be necessary to run the machine a considerable time before a reading can be taken, and after altering the load on the machine to run it for a considerable time before taking any new readings for that new load. I presume that in the two tests referred to on page 294—the short-circuit test and the load test—the stator current was the same in each case; it is not stated, but I think one would infer that the short-circuit test was adjusted so that the short-circuit current was equal to the full-load current. On page 295, under "Electrical methods," I suggest that the word "law" in the second line should be "fact." An important point throughout the paper is the relative advantages and disadvantages of the anemometer method of measuring the air delivery. One obvious advantage, I think, is that the anemometer measures the air velocity parallel to the axis of the anemometer, whereas a heated wire would be cooled by air flowing in the trunk, not necessarily along the axis; but I presume that in this case any velocity the air might have otherwise than parallel to the axis would be so small as to make that error negligible. It appears to me that one of the disadvantages of this method is the laborious manner of taking a great number of anemometer readings over the cross-section. However expert the operator might become, it seems to me a very cumbersome method of finding the air delivery. Instead of reading the anemometer over a great number of squares, some method should be devised whereby one could get the whole effect over the cross-section in one reading. I presume that that could be done by the electrical anemometer, by suitably distributing the hot wire over the whole cross-section, so that each square would have the same amount of hot wire in it. One could in this way get the total discharge of air by a single reading of the galvanometer in the Wheatstone bridge arrangement. I am a little puzzled by the reference to the frictional loss of anemometers. It seems to me that if the frictional loss has not changed since the anemometer was originally calibrated, no error will be introduced. I presume that the anemometers are calibrated by tests, so that unless the friction has changed since the anemometer was made it does not matter whether it was 3 per cent or 5 per cent. It is rather suggested in the paper that if an anemometer had 3 per cent friction there would be 3 per cent error. Another point I should like cleared up is on page 296, col. 1, in regard to the inertia effects of anemometers. The authors state "The retardation period is decidedly longer than the acceleration period." There may be some simple explanation of this, but at first sight it looks rather contrary to the laws of mechanics. With regard to Fig. 4 on page 298, Curve A suggests that, after all, the variation over the cross-section of the trunk is only small, and that after a few experiments with a trunk one could find a place where one anemometer would give a mean reading. The variation of Curve A, expressed as a percentage, is not very great over the surface, and if one were to place the anemometer where the reading has about the average value, or if one were to place it in the centre and work out the reduction coefficient, one could, after a little experience, determine the total air delivery, with confidence, from the single reading. My remarks about the cumbersomeness of the method of moving the anemometer into a large number of positions applies also to the temperature readings. Apparently the authors use a considerable number of thermometers over various points of the cross-section, but I do not think they say how much the temperature varies over the cross-section. There, again, I think an electrical method could be used; if the wire is stretched uniformly over the whole cross-section of the trunk we could by a single reading get the temperature. There may, however, be some disadvantage that I have not suspected.

I notice the authors refer throughout the paper to inches of mercury for the barometer reading, and all their reduction formulæ are based on inches. If that is so, what is the object of taking 29·92 inches of mercury as the standard ? Surely if all the work is going to be in inches, one might just as well take as a standard 30 inches ; even if the corresponding corrections were not made the error introduced thereby is only $\frac{1}{4}$ of one per cent ; 29·92 inches suggests that the authors are not really working in inches, but in centimetres.

**Captain A. H. Law :** In my opinion this paper will place on a satisfactory basis what has for a long time been a matter of discussion between the turbine builder and the electrical designer. My own firm have had two or three cases in which the efficiencies of alternators designed by other manufacturers have been questioned, and since 1910 I have constantly used air calorimetry for determining the efficiency of alternators of all sizes. Now that a description of these methods is to be on the records of the Institution there will be less hesitation on the part of persons interested in accepting them as accurate. The precautions which must be taken are clearly shown by the authors and I have little to add to them. It is worth remembering, however, when an anemometer is used that this instrument is usually calibrated with cold air. In certain cases it has been found, possibly owing to varying friction in the bearings of the instrument, that this calibration is not strictly accurate for air of the temperature which is usually reached in the outlet from turbo-alternators. The method described by the authors, by which a chimney is fitted to the outlet and the velocity measured by an anemometer in this outlet systematically over a number of equal squares, has been found to give good results. I am especially interested in the method which the authors describe as the " calibrated air-temperature " method. This method was used by Messrs. Parsons in the year 1910 when it became necessary accurately to determine the efficiency of some large alternators to which new and up-to-date turbines were being fitted. The method was almost exactly that described by the authors. The alternators were run as motors and the power input and temperature rise accurately measured. This gave an indication of the quantity of air passing through the alternators, which were then run on load and the efficiency determined in the manner described in the paper. The method was also used in the year 1913 when there was a question of the efficiency of some large single-phase machines built on the Continent. The efficiency of these machines had been guaranteed at a certain figure, but as they were designed for generating single-phase current their efficiency was doubted. It was found, as was expected, that the efficiency was considerably lower than the guaranteed figure. A method of determining efficiency which includes stray losses is of special importance in the case of single-phase machines where these losses may be very considerable. I am not quite in agreement with the authors where they suggest that when using the " calibrated air-temperature " method, the efficiency cannot be determined solely by tests on site. In both the above cases the efficiency was determined solely in this way, and eventually figures were arrived at which satisfied all parties. It may be of interest to describe the method we employed for running the alternator up to speed as a synchronous motor, as there are obvious difficulties in getting a large machine of this type up to synchronous speed and paralleling it in on the system independently of the turbine. This was got over

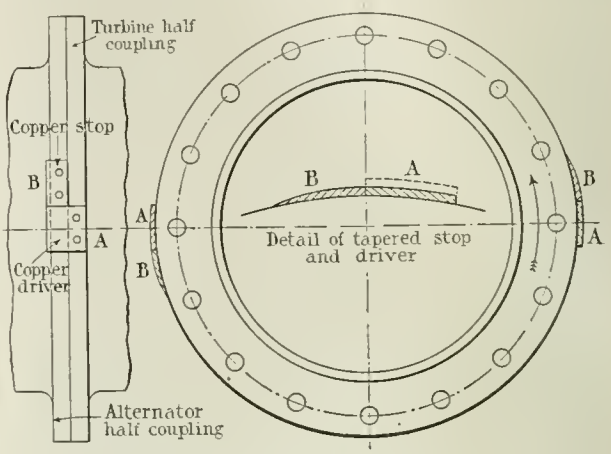


Fig. A.—Coupling showing drivers for slipping turbine when motoring the alternator.

by the use of the device shown in Fig. A herewith. The coupling bolts which normally join the halves of the flexible coupling were removed, and the halves of the coupling were connected by a soft copper driving strip A A riveted to the turbine half of the coupling. This strip engaged with a tapered projecting stop

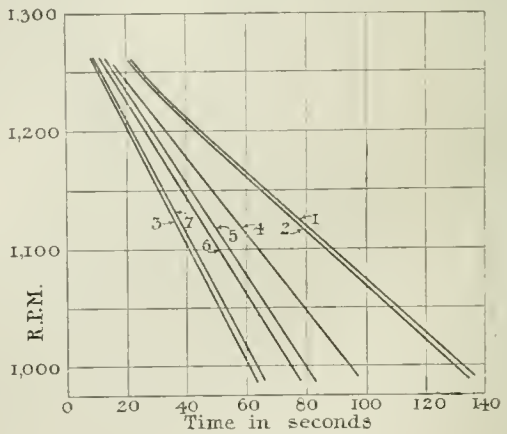


Fig. B.—Retardation tests.

piece on the alternator part of the coupling, as shown at B B. When the turbine was started, A drove B and the alternator was run up to speed and paralleled. The turbine was then shut down, when B ran ahead of A, and, being tapered, forced outwards that part of A which projected over the alternator half coupling, thus freeing the alternator from the turbine. The turbine was then run under steam merely to supply oil to the bearings while measurements were being made

of the power supplied to the alternator running as a motor. The authors on page 301, par. 4, express doubts as to the accuracy of the retardation method of obtaining the no-load losses. I cannot agree that this method is inaccurate if it is carefully done. It was used in 1912 for determining the no-load losses on one of the 5,000-kw. turbo-alternators at Carville. Fig. B shows a set of retardation tests which were made on one of these alternators. No. 1 shows the rate of slowing up of the turbo-alternator when the alternator was unexcited. No. 2 is a similar curve with the alternator running at about 1/10th of its rated voltage. No. 3 is the deceleration curve at 1/10th voltage and with a load of 100 kw. as a calibration. Nos. 4, 5, 6, and 7 are deceleration curves with no load and at different terminal voltages. Curve 3, when used in conjunction with calculations of the stored energy of the parts, supplies a calibration for determining the no-load

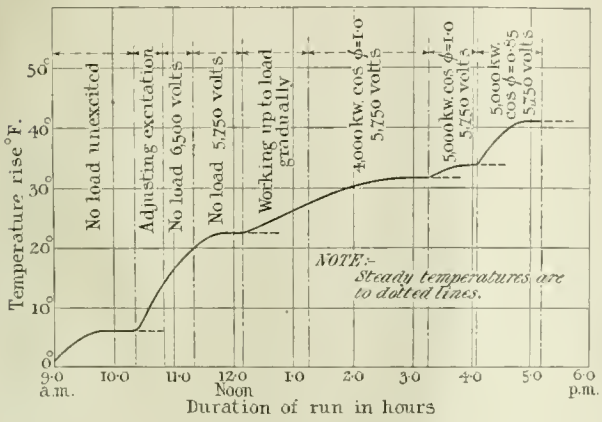


FIG. C.—Curve showing temperature rise of outlet air above inlet air.

losses for the different voltages represented by Curves 4, 5, 6, and 7; or, in other words, the accuracy of the calculations of the stored energy of the parts is checked by a retardation curve taken with a small amount of accurately measured load on the alternator. It will be noted that the normal speed of the machine is 1,200 r.p.m.; in taking these tests the speed was run up to over 1,300 r.p.m., the readings commencing at about 1,260 r.p.m. The voltage of the alternator was kept steady by hand manipulation of the regulating rheostat. Fig. C shows the final stage of the efficiency determination, the whole of the tests having been carried out between 9 a.m. and 5 p.m. In each case the curves were artificially steadied by raising the voltage or load to a rather greater amount than that shown opposite to each flat portion of the curve. As soon as the estimated temperature was reached the load was brought to the stated amount, and in this way steady readings were quickly obtained. It has been suggested to fit, at some point in the air ducts of the alternator, resistance grids which can be supplied with any desired amount of electrical energy. Thus, for the purpose of calibration, the temperature difference can be increased to an amount approximately equal to the full-load temperature difference. There are two additional minor causes of error which are not referred to in Appendix I. One of these is the loss in the exciter field-rheostat, main-field-rheostat, exciter field-coils, commutator, etc. These can, of course, easily be added. In addition there is a very small "throw-away" velocity loss in the air rejected from the alternator.

**Professor E. W. Marchant**: To me, one of the most interesting facts in the paper is that the stray loss of these alternators is so large. Electrical engineers have always flattered themselves that they were able to calculate exactly the losses in machines. Now we have a case where there is a stray loss which is 40 per cent of the total loss in the machine. We have got to start all over again and find out to what this stray loss is due, so that we may estimate its amount. I want, however, to refer more particularly to the methods of measuring air velocities. Mr. F. J. Teago carried out in my laboratory some 5 or 6 years ago a number of tests on the cooling of transformers by air blast, and used a Pitot tube very similar to that which has been described in the paper. He also made a number of investigations on the uniformity of flow of air along pipes. He found he was able to get an almost uniform flow by having wire gauze baffles at each end of the pipes—the curves of pressure across the pipe were even straighter than those given in the paper. Possibly wire gauze would not be suitable in experiments of this kind on account of the additional resistance which would be offered to the passage of the air. He used a very simple gauge for measuring the difference in air pressure between the two parts of the Pitot tube. It worked extremely well and was very sensitive. Instead of having an inclined gauge such as is very often used for this purpose, or the Roberts gauge which has been described, he used a gauge somewhat similar in principle to the Roberts gauge but with a vertical U-tube connecting the two expanded tops of the U. The two limbs of the gauge were filled respectively with a coloured solution of water and a mixture of toluol and chloroform. The object of using the mixture was to get two liquids having almost exactly the same density, and between which there was a definite meniscus, so that one could see the point of contact between them. This gauge answers as a magnifying gauge. Neglecting differences in density, the magnification of the motion at the meniscus is equal to the ratio of the area of the expanded top to the area of the tube.* He used this gauge in all the tests and found the method quite satisfactory. I should like to ask whether any investigation has been made as to the effect of the anemometer itself on the flow of air through the pipe. I have never had much faith in anemometers—and I doubt whether they will be very satisfactory in measurements of this kind. Those I have used have always proved somewhat uncertain in their behaviour.

**Major A. M. Taylor**: I should like to ask the authors whether the stray loss is obtained by deducting the known losses from the total measured loss. If it is, any error incurred in measuring the total loss—say, for example, a 10 per cent error—will be the error in the measurement of the stray loss. But this is

* *Journal I.E.E.*, 1914, vol. 52, p. 563.

only true provided that the "known" losses are really very closely known (since these stray losses are obtained by a process of subtraction), and provided that the stray losses are quite a large proportion of the total losses. Taking the authors' own figures for the various errors investigated, it would seem as though the aggregate error in the measurement of the total losses would not be likely to exceed 8 to 10 per cent. It is well to bear in mind that the loss being investigated is about 1 to 1½ per cent of the output of the alternator. Compared with the less-known losses occurring on the steam side, it might seem to steam engineers rather like splitting hairs to be analysing such losses as these; and the question arises as to whether the talents of the two authors would not be better directed in analysing the steam losses which aggregate from 15 to 20 per cent and do not seem to lend themselves readily either to exact measurement or to calculation. I mention this point because the paper is entitled "Determination of the Efficiency of the Turbo-Alternator," which presumably includes the steam side, nothing being said, however, about this in the paper. Of the two methods described of measuring the electrical losses, both of which seem to be sufficiently accurate, the "air-heating" method appears to have the distinct advantage of allowing tests to be conducted on site. As regards the employment of the perforated metal screens for getting the curve "A" shown in Fig. 4, we have to accept the authors' statement that the baffles have "no appreciable effect" on the temperature of the alternator. I suggest that if, instead of plain perforated screens, a series of guiding blades were designed like the blades of a turbine, so as to transfer, without shock or undue friction, the right-to-left components of the velocity of the air into vertical components, the same results might be attained as with the authors' perforated screens and without the throttling effect which is to be expected with these screens. With reference, again, to the losses occurring on the steam side, would it not be possible to measure some of those losses by electrical methods? Take, for example, the blade friction-losses, which are given by one authority at from 6 to 30 per cent. On a 5,000-kw. set even this 6 per cent would mean 300 kw., and the dissipation of this large energy loss must mean a very considerable increase in the temperature of the surface of the blades. Would it not be possible to design thermo-couples which could be so placed as to show this rise in temperature compared with the temperature of the steam in the centre of the passage between the two blades? A similar method might be adopted for the other losses in the turbines.

**Mr. C. C. Paterson**: There is no mention in the paper of the amount of heat which passes through the bed-plate into the foundations. I should have thought this formed a channel of loss from the machine which would be an appreciable factor in these tests, taking a long time to reach a steady condition.

**Professor J. T. MacGregor-Morris**: In order to get an accurate determination of the efficiency of an alternator it is much better to measure the actual loss in the machine than to measure separately the large input and output. I think it was Mr. Mordey who first suggested this method in connection with transformers, measuring the temperature of the transformer, using it as a kind of calorimeter. Then we passed to Threlfall's method, and now we come to its very neat application by the present authors. As has been pointed out, this is of exceedingly easy application because of the casing which turbo-alternators now always have. As the authors have referred to some work of mine in connection with the electrical measurement of wind velocity, I will confine my remarks to that point. I should like to say a word or two about the inclination of the wires in the stream. It has been suggested that accurate measurements will not be obtained if the wires are not exactly at right angles to the flow of air. With regard to that I would say that the arrangement given by the authors for getting the stream fairly uniform could be considerably improved without in any way increasing the drop in pressure. Anybody who is familiar with aeronautical work in wind tunnels could at once suggest modifications to increase the uniformity of the stream. If that were done, it would be better in all ways for this particular test, yet the variation across the cross-section, as Professor Howe has pointed out, is not great. Professor Howe has indicated that a hot-wire arrangement might be employed to measure the average velocity over the whole cross-section, and when the authors showed me this paper some time ago I had already devised an arrangement by means of which one could make a single measurement to give the difference in temperature between the inlet and outlet, and to give by a single reading the other quantity which is wanted. In connection with Equation (2) on page 299 an attempt is made to measure the velocity. I suggest it would be much better to use an instrument which would measure the mass flow. I believe the whole of the measurement could quite easily be made in two minutes and I entirely agree with the authors that this method is one which certainly should be developed as much as possible.

**Dr. F. T. Chapman**: There is another point which is closely related to that mentioned by Mr. Paterson, namely, that in tests on site the alternator is mounted on the same bed-plate as the hot steam turbine, and one would expect a certain amount of heat would pass from the turbine to the alternator. I should like to know whether the authors have considered this, and whether they have made any measurements from which they have come to the conclusion that it is negligible.

(*Communicated*): Since the meeting, I have been able to have some readings taken on a 3,000-kw. turbo-alternator at St. Marylebone electricity works, through the kindness of Mr. Leonard. The machine had been running all day, and when the readings were taken in the evening it was carrying about 80 per cent of its rated load. There was then a drop of 30 degrees C. in the temperature of the bed-plate in a length of about 16 inches from the turbine towards the alternator. Along the shaft there will be a still steeper temperature gradient, so that there must be a considerable heat flow towards the alternator. It is possible that this supply of heat compensates more or less for the loss which occurs via the foundations, but it would be

useful to know whether the net gain or loss of heat is appreciable. The authors have referred to the use of resistance coils for measuring the temperatures of the air at inlet and outlet. By the use of three such coils it would perhaps be possible to eliminate altogether the necessity for velocity measurements and corrections for humidity, barometric pressure, etc. Suppose A, B, and C are the three resistances; A is placed in the inlet, B low down in the discharge trunk, and C further down stream near the opening. B and C are sufficiently far apart to enable a heater to be inserted between them. Let $T_a$, $T_b$, and $T_c$ be the temperatures of the three coils respectively, $W_m$ the watts lost in the machine, and $W_h$ the watts lost in the heater; then

$$W_m = W_h \frac{T_b - T_a}{T_c - T_b}.$$

Since small values of $(T_c - T_b)$ can be measured with accuracy, $W_h$ need not be large, and the heater would only be required for a few minutes at the end of the test after the value of $T_b - T_a$ had become steady.

**Mr. Ll. B. Atkinson**: There is just one point I would make, because this anemometer question has raised doubts in many minds. Some very simple methods have been mentioned of measuring temperatures electrically without necessarily measuring the volume of air; but the use of an anemometer to measure the velocity of air passing is, to my mind, rather like using an ordinary house meter to measure an electric current. Some time ago I made, for the purpose of measuring how much air passed up some chimneys, a simple deflection instrument which I calibrated with an anemometer, and by which it is possible to go over the whole area of the channel to be measured and take the deflections very rapidly. The deflection with such an instrument could be obtained almost instantaneously, and to wait a quarter of a minute at each point in order to get a reading with an instrument that certainly has the known disadvantage of an anemometer seems quite unnecessary. I remember we used to have, in the early days of electricity, no regard for any instrument that did not operate according to some definite law. Then we suddenly adopted the simple method of taking an instrument and calibrating it. So I suggest if we want to measure the air flow rapidly, not to bother with the anemometer at all but get a deflection instrument, which is quite simple to make, calibrate it once for all with an anemometer, and then go rapidly over the whole area and take the deflections.

**Mr. E. G. C. Barton**: In the early eighties a discussion raged over the Ferranti alternator, Sir William Siemens claiming that alternating-current machines were less efficient than direct-current machines. Dr. Ferranti appealed to the heating test and it was made in an enclosed box, by measuring the temperature rise of its limited air contents. It would be interesting to obtain details of that test from Dr. Ferranti.

**Mr. A. E. Gott**: Owing to the difficulties experienced in accurate measurement of air volumes and velocities the proposed method of testing resolves itself into measuring very small differences of pressure such as given by Pitot tubes, and the various instruments devised for the purpose are generally unsatisfactory. In exceptional cases of mine ventilation in which about 200,000 cubic feet per minute move with a total pressure of $\frac{3}{8}$ inch water gauge it is almost impracticable to determine the efficiency with reasonable accuracy. The attempts to devise instruments for continuously indicating and recording low total pressure for mines, as revealed by patent specifications and those in use, are not good and are subject to large errors. I have studied the problem of measuring low pressure for Pitot tube work and decided that a reliable instrument could be made if a compensating medium consisting of some material sinkable in mercury but not dissolved by it could be used, but owing to the cost the idea was abandoned. I have since found that the error which it was intended to compensate obeys the same law as that of the scale of the proposed instrument and may be compounded with it. Such an instrument may therefore be developed.

**Mr. A. Stubbs** (*communicated*): It is rather an unconventional procedure to have to resort to thermodynamical considerations of gases in order to determine certain electromagnetic quantities; yet in some ways it certainly seems to be the most logical and scientific, for an effort is made to measure directly the loss which is a small difference between the input and output power. Usually thermo-dynamic quantities are much more difficult to measure than electrical, for electricity is the most mathematical of the engineering sciences. It is therefore somewhat remarkable that "the air-heating" method and the "calibrated air-temperature" method should have yielded such excellent results as are given in the paper. I feel that it is only by exercising great precautions that misleading results have been avoided, and I am not convinced that the methods referred to should be adopted as the standard efficiency tests. It is rather a weak point in the "calibrated air-temperature" method that core-loss readings should have to be determined by, say, a driving motor, as the present tendency seems to be for the alternator manufacturer to build his own turbine and to test the unit complete, and in this way the great expense of having to provide a separate test bed for the particular alternator is saved, not to mention the test plant that would be necessary to drive alternators over such a large range of speeds and powers as to-day exist. If the curves A and B in Fig. 4 are taken under similar conditions, they seem to suggest that the effect of the baffle plates and chimney is to distribute evenly the air velocity and not to produce any back pressure. Should there be any back pressure and a consequent rise in temperature, it is necessary to inquire how much it would react upon the efficiency (for efficiency to some extent is a function of the temperature of the machine) and if allowance can be made for the same. I would suggest that whilst the efficiency of the alternator is a useful figure for the sales people, yet the designer must have a complete segregation of the losses of the machine. It is going to be rather a lengthy business to separate the losses by, say, the "heated air method," as it is essential to wait until steady conditions are attained, which may take as long as 6 hours upon some machines, and when a series

of such tests are to be made, many days of continuous work may be required. This disadvantage of having to wait for steady conditions seems to have been hidden. The large heat capacity of these machines and the inevitable variations in the atmospheric conditions which are to be found in any test room or power house may easily lead to almost unavoidable errors. During the segregation of losses test the danger from hot spots upon short-circuit continuous runs, which is referred to in the paper, must be guarded against, and since these spots may be hard to find, damage may have been done which under ordinary conditions would not occur. Neither of the methods given by the authors takes account of the kinetic loss due to windage, viz. $\frac{1}{2}$ MV$^2$, which in a 6,000-k.v.a. machine is of the order of 20 to 30 horse-power; and although this is only $\frac{1}{2}$ per cent of the full-load capacity of the machine, yet it is important as it is independent of the load. The authors dismiss rather lightly the segregation of losses by the retardation method, stating (page 301) that: "Apart from the difficulty of ascertaining the losses in this way an accurate result is not to be expected therefrom." This is very remarkable, as I have found the method to be very exact and convenient. The retardation curves for an alternator under the various conditions required may take anything from 7 minutes to half an hour to die down from just over full speed to half speed, and during this time the speed and time intervals may be accurately recorded where the test plate is under systematic supervision. All the losses of the turbine and the alternator may be separated in this way, either upon the test plate or at any future time on site, but the over-speed tests should first have been carried out. It is true that flux conditions upon retardation tests are not exactly the same as upon load, yet by using the retardation curves to correct one another, together with a knowledge of the design of the machine, a very good figure can be obtained for the overall efficiency. The time taken on a full set of retardation tests need not exceed 8 hours, and no additional test plant is required. It is quite unnecessary to calculate the inertia of the moving parts of the turbine and alternator, and all that is required is to compare the differential coefficients of the various retardation curves.

(The authors' reply to this discussion will be found on page 313.)

## South Midland Centre, at Birmingham, 5 March, 1919.

**Mr. R. Orsettich**: The paper deals with a matter of exceptional importance to those who are engaged in the carrying-out of large contracts, including the supply of turbo-alternators. Such contracts are often carried out by two or more firms, one of which makes the steam turbine, another the electrical generator, and perhaps a third the condensing plant. The guarantees are given in the form of steam consumption in lb. per kilowatt-hour generated. When one further considers that the penalties for exceeding the guaranteed figures are often as high as £10,000 per lb. of steam, it is at once apparent how important it is that the respective liability of the different firms should be clearly ascertainable. The methods available up to the present in determining the efficiency of these machines are exceedingly poor, in so far as there is no well-determined and recognized means of arriving at the figure of the efficiency, and therefore no way of demonstrating whether the conditions of the contract are fulfilled or not. Various methods were used by different generator makers in stating the efficiency, all more or less including a fictitious value or conventional efficiency intended mainly to include such losses as could be readily measured, and also those which could not be measured, as a multiple of one of the first ones. Owing to the fact that efficiency figures stated in this way could not be compared, the makers of the generators were asked by the makers of the steam turbines to exchange views and endeavour to standardize methods of stating the efficiency and the tests required to prove it. It was remarkable that three firms at that time stated that they were experimenting with measurements of the cooling air as the only reliable method of determining the losses, and that this method was recommended for further investigation. Great credit is therefore due to the authors for being the first to publish the result of their inquiries and for the great accuracy shown in the results of the experiments. The one striking fact in examining the various measurements of the losses is the very large value of the stray losses. These losses have not been ascertained by direct measurement, nor is it yet quite clear where they take place or to what peculiarity of construction they are due. They seem to share the nature of copper losses in so far as they are dependent upon the load, but they appear to be taking place mainly in the iron portion of the machine, and are therefore really iron losses. Some engineers usually put down these stray losses as a multiple of the copper losses, but Mr. Hobart, in the last edition of the "Standard Handbook," states that a probable and fairly accurate value is obtained if they are taken as equal to one-half of the iron losses. It would be interesting if the authors would give the ratio of the stray losses to the copper as well as to the iron losses. There is, however, no doubt, that, owing to there being no basis for calculating such losses, the position of the designer is very unsatisfactory, and that the argument is one for research. Considering the difficulties of an accurate measurement of the air by means of the anemometer, and the error which is introduced by such inaccuracy, I have been wondering whether it would not be possible to eliminate the error in the instrument by taking a reading with the same instrument both at the intake and at the exhaust of the generator. The ratio of the two readings would then give a ratio of the volumes of the cold and hot air, and this would then be equal to the inverted ratio of the absolute temperatures of the air at the two ends. Such reading could be taken in the trunk of the ventilating air of the machine as easily

as at the extension on top of the machine. The main objection to the air tests described in the paper is to be found in the fact that to measure the losses one must have the machine on load and therefore driven by the turbine. This condition only obtains after the whole plant has been delivered and erected on site, and the tests described are only possible when the contract is materially completed. What is of real importance to the manufacturer is a test which enables him to prove to himself and to others that his portion of the plant is correct before he despatches the machine from his shop, and that any adjustments which may be required should be done before delivery.

**Mr. F. J. Moffett**: The authors point out the great importance of the stray losses which, with the existing method of determining the separate losses in the alternator, are not measured but arrived at by what may be called scientific guesswork. It would be of great interest if they could give more information as to the character of these stray losses and indicate as far as possible to what cause they are due. On page 294 the authors state that from the measurement of the total losses by their air-heating method the separate losses can be deduced. I should like further information as to how these are separated out. On page 297 it is stated that when making the air measurement it was found that the air was eddying violently in some places. This points to the need for care in the design of the air passages, since with the large volumes of air passing there is possibility of loss from air eddies or vortices. For many years I have taken an interest in anemometers in connection with the measurement of power available from the wind, and have used for this purpose a recording instrument which was calibrated at Kew and found to be accurate within 2 per cent. The instrument consists of a vane mounted so as to be free to turn about a vertical axis. There is an opening in the nose of the vane which is connected through a mercury gland to a tube transmitting the dynamic pressure to a bellows make of gold-beater's skin. The vane being free to revolve takes up a position parallel to the stream lines. It appears to me that the method adopted in the paper for measurement of the alternator losses is capable of being adapted to provide a continuous record of a turbo set when in service. If recording instruments to measure the air velocity, air temperature-rise, electrical output of alternator and steam input to turbine were all arranged to record on the same drum, the various losses could be ascertained at any time by drawing a vertical line on the drum. The Kent steam meter which works on the Venturi principle of measuring the difference in pressure between the two sides of a constriction in the pipe, gives fairly accurate readings. From such a combination of records valuable information could readily be obtained as to the condition of the turbine and the alternator. Any change in efficiency due in the turbine to blade troubles or other cause, or in the alternator to stoppage of air ducts or to coating of the walls of the ducts with a covering of non-conducting deposit, would be noticed and steps taken to remedy the trouble. Air does not appear to me to be the most effective cooling medium to use for removing the heat due to the various losses. I looked up the specific heats of various gases and liquids, and among the gases I found that at constant pressure hydrogen has a specific heat of 3·4, ammonia 0·53, and methane 0·6, whilst air is only 0·24. Among the liquids water is of course unity, whilst petroleum is 0·5, methylated spirit 0·57, and glycerine 0·57. If any of these gases or liquids were used it would be necessary to conduct the cooling as a closed circuit system. The cooling medium after passing through the air passages of the alternator would have to be reduced in temperature by passing through a feed-water heater or similar arrangement. This alone would somewhat increase the total efficiency of generation, as the heat due to the losses would be returned to the boilers in the feed water. Both oil and water cooling have been used for a considerable time in connection with transformers working at the highest voltages, and I believe it is an open secret that the Admiralty have, during the war, made extensive use of electrically-driven pumps which are submerged to the required depths during salvage operations. The motors are designed for alternating current and the rotors actually revolve in water. In addition to the variation in efficiency of different cooling media, due to their specific heat, there is, I believe, a variation due to what may be called "the coefficient of heat transference," that is, the rate at which the cooling medium is able to absorb the heat as against the quantity, which depends on the specific heat.

**Mr. R. G. Jakeman**: Perhaps the most noticeable feature of this paper is the extreme care that the authors have used in obtaining their results. In fact, it is doubtful whether most people would be able to use such care, and no doubt that is the reason that the accuracy of the anemometer is generally regarded with so much suspicion. It is, however, remarkable that the anemometer has improved so much of late years. The makers now guarantee them within 1 per cent, but 7 years ago, speaking in the discussion on a paper before the Institution,* Mr. E. H. Rayner, of the National Physical Laborabory, stated that an anemometer with an error of less than 10 per cent was an extraordinarily good instrument. The "calibrated air-temperature" method, however, appears to do away with all instruments of precision. All that is required is a discharge trunk, a few dozen thermometers, and a ball of string. As far as it goes, however, the paper is not of much use to the manufacturer. It only enables us to find out the value of the losses after the machine has been built, but it does not inform us how to predict these losses so that the manufacturer can guarantee the efficiency in the tendering stage. I hope the authors will continue their experiments and will determine how the stray loss varies with the load, voltage, and speed. In one of the slides shown, we saw that in two machines of the same output the stray loss was 23·5 per cent and 40·3 per cent respectively. Perhaps, by means of the tests mentioned above, some relation could be found between the stray loss and the stator copper loss. It would be interesting if the authors could tell us the outputs of the machines on which the tests shown in the paper were carried out. With regard

* *Journal I.E.E.*, 1912, vol. 48, p. 722.

to the "calibrated air-temperature" method, no correction has been mentioned for a variation in the temperature of the inlet air, although this might in some cases be quite considerable. It is interesting to note that after test (2) has been carried out, the rise in test (1) gives the windage loss, and the figures thus obtained can be used to check other methods of finding the same loss. The authors mention the difficulty of determining the core loss accurately when a driving motor is used, but this can be avoided by providing a clutch between the motor and the machine to be tested. The machine can then be run up to about half speed by means of the driving motor, synchronized with an alternator, and the clutch disengaged. The machine then runs as a synchronous motor and the frequency can be increased to the normal. A curve can then be plotted of the watts input against the voltage, the latter being reduced until the machine falls out of step. By continuing the curve back to the zero ordinate, the friction and windage loss is obtained. The saturation curve can of course be taken at any convenient speed while the machine is being driven by the driving motor.

**Dr. M. L. Kahn**: I fully agree with the authors that the most satisfactory method evolved at present to determine the efficiency of turbo-alternators is to measure the total loss in the way described in the paper as the air-heating method. One precaution seems not to have been specifically mentioned in the paper. It is essential to run the machine for some time at each particular load on which the efficiency is to be ascertained, so that the temperature of the masses of iron and copper in the machine is fairly steady and no heat produced by the loss in the alternator is absorbed by these masses. Otherwise this part of the losses would not be recorded by the temperature rise of the cooling air. Particularly interesting is Table 6, where the different methods of measuring the efficiency are compared. The fact that the summation of losses measured in the form prescribed by the American Institute gives, in the three instances quoted, results which fairly well agree with the air-heating method does not in any way prove that this method would give equally good results in other cases, as the conditions for stray losses on short-circuits and full load are different. There seems to be sometimes a misconception with regard to these stray losses; they are often classed with the copper losses in the stator and expressed by adding a certain fixed percentage to these losses, while they are really to a large extent increased iron losses. That these losses have no fixed relation to the stator copper losses can easily be seen if one considers that by decreasing the copper weight of the stator winding the stator losses are practically unaffected. If the stator copper losses are based on the ohmic resistance measured on the test bed with direct-current instruments, when determining the efficiency by a summation of separate losses, the actual losses in the stator copper with full alternating current flowing would of course be higher, due to the uneven distribution of the alternating current in the conductors. This difference accounts, however, only for a small part of the stray losses, and the difference can as a matter of fact be greatly reduced by using stranded conductors for the whole of the windings without affecting the total stray losses in the machine materially. The stray losses in the iron part of the turbo-alternator are mainly made up of the following separate items:—

(1) Increase in the stator core and teeth loss above the losses measured on full voltage no load due to the increase of flux at full load above the no-load flux by the reactance of the stator winding. As the reactance of large turbo-alternators is of the order of, say, 12 per cent, the increase in flux at full-load power factor (0·8) is about 7 per cent, and the corresponding increase in the stator iron losses due to this is about 15 per cent or more.

(2) Increased teeth loss due to flux distortion. The iron losses in the teeth are still further increased by the distortion of the field, due to the armature reaction. The field may have a symmetrical sine wave-form on no load, while on full load this wave-form is distorted. The maximum flux density in the stator teeth is therefore higher at full load than at no load, with a corresponding increase in the losses in the stator teeth.

(3) Losses in the rotor surface due to flux variations set up by the pulsation of the magnetomotive force of the stator. In the case of laminated rotors this flux pulsation can permeate the rotor core itself and cause variations in the field current, as has been demonstrated by oscillograph records.

(4) Losses due to the flux fluctuations set up by the magnetomotive force of the end connections of the stator winding. These losses take place in the cast-iron stator end-plates, in the end stampings on each side of the stator core, in the end caps of the rotor, and in the cast-iron shields enclosing the stator end-windings.

(5) Losses in the metallic parts of the winding supports which are fitted to prevent destruction of the end windings in case of short-circuit.

If one considers these losses singly, one finds that some of them will be larger when the machine is operated on short-circuit than they would be when running at full voltage on full load, Nos. (3) and (4) belong to this class, while the losses classed as (1) and (2) are presumably higher at full voltage on full load than the corresponding losses on short-circuit. These discrepancies may or may not counterbalance one another. This fact is clearly brought out in Table 7, where it is shown that stray losses on load measured by the air-heating method are sometimes larger and sometimes smaller than the stray losses on short-circuit. In the paper one particular kind of stray loss is mentioned which is different on load and on short-circuit, viz. the loss in the laminations on the end of the stator core. I venture to suggest an explanation of this discrepancy. The losses are caused by the flux set up by the magnetomotive force of the end windings of the stator. The path of the flux is partly made up by air and partly by an iron magnetic circuit, consisting of the end covers enclosing the stator winding, the rotor end caps, and the stator end-plates and laminations. On full voltage the end caps of the rotor are saturated and offer a path of great reluctance to the flux. On short-circuit they are not saturated and offer a path of high magnetic conductivity. The flux set up by the magnetomotive force of the end winding is there-

fore much larger on short-circuit, when it finds an easier path than on full voltage, where the magnetic saturation of the rotor caps offers an obstruction. Considering the great importance of the large turbo-alternator and its development to larger and larger sizes, experimental investigations of these stray losses which can be made by comparing the loss figures obtained by the different methods described in the paper on a number of machines of different design would be of great value, as we can see from the figures given for the stray losses in the paper that they constitute a considerable proportion of the total loss in the machine. If more were known about these losses they could conceivably be reduced, so that the maximum possible output of a single generator at given speeds could be increased. I hope that the authors of the paper will continue their work in this direction.

**Mr. C. V. Peake**: Referring to steam-consumption tests, I understand that it is possible to convert the steam consumption of the turbine when running light into actual brake horse-power, and thus into kilowatts. If this be so, then it would seem that the alternator efficiency might be determined by taking the following steam consumptions:—(1) Running light and uncoupled; (2) running light but coupled to the alternator, the latter being unexcited; (3) running light with the alternator over-excited by an amount necessary to balance the voltage drop due to resistance and reactance on the specified power factor. The results obtained by subtracting reading No. (1) from No. (2) would give the windage friction and alternator bearing losses, and subtracting No. (2) from No. (3) would give the iron loss.

**Mr. R. J. Kaula**: The authors are to be congratulated on their candour in setting out the full facts as regards the stray losses found by their tests. Turbine makers and designers will be very thankful to them, as they have been greatly puzzled in the past as to the true efficiency of alternators. They were in the unfortunate position of having to accept generator efficiencies as determined by light-load methods, and to account for the remaining losses in the units in the steam as best they could. The authors do not take account of the work represented by the kinetic energy contained in the air leaving the machine. This should, of course, be added to the loss as determined by the temperature rise of the air, but the amount is probably very small. In reading air pressures or velocity in the manner described, the arm of the man taking the readings would appear to be likely to block up some of the squares and thereby increase the rate of air flow through the remaining openings.

**Dr. S. F. Barclay** and **Dr. S. P. Smith** (*in reply to the discussions before The Institution and the South Midland Centre*): In our reply, we propose to deal collectively with certain matters that have been raised.

*Stray loss.*—Professor Howe very properly draws attention to the small amount that has been published on this subject. We agree with him that the flux distortion caused by armature reaction is probably a main cause of this loss. Though Professor Marchant is surprised at the magnitude of the stray loss, designers have long been aware of its serious nature. In reply to Major Taylor's and Mr. Moffett's question, the stray loss is obtained by deducting the separately-measured from the total measured losses. Of course, an error of 10 per cent in the latter would give a corresponding error in the stray loss, but in the methods discussed an error of this magnitude ought never to arise. Mr. Orsettich commented on the large value of the stray loss and thought that it occurred largely in the iron. We agree. Our experience does not confirm that the stray loss can be taken as equal to half the iron loss. In six turbo-alternators ranging from 3,000 to 5,000 kw. and designed for low iron loss, we found that the average value of the ratio (stray loss) : (iron loss) was very nearly 1·5, the iron loss being taken at normal volts on open circuit. In these six machines the mean value of the ratio of the stray loss to the ohmic copper loss was 3·5, the ohmic loss being calculated for the copper hot, and the stray loss measured on short-circuit. These values would, of course, not apply to abnormal cases. With reference to Dr. Kahn's remarks, we think that the practice of expressing the stray loss in terms of the stator copper loss is justifiable because in the measurement of the stray loss on short-circuit it is found that it varies approximately as the square of the stator current. His analysis of the seats of stray loss is very useful, though we think that his remark that the end bells are not saturated on short-circuit may not be true in many cases because of the large magnetomotive forces present under this condition—possibly the power factor largely accounts for the difference between short-circuit and load conditions by shifting the position of armature reaction. In reply to Mr. Kaula's remarks, we hope that a standard method will be adopted whereby the alternator losses can be correctly determined, and so enable the turbine maker also to obtain an accurate value for his losses.

*Criticism of anemometer.*—We agree with Professor Howe that the air-heating method as proposed may appear cumbersome and that it would be admirable if the desired result could be obtained with a single reading, but our experience has not as yet enabled us to progress beyond the stage discussed in the paper. It would be misleading to take Fig. 4 as a fair average or to base a single reading thereon. In speaking of a possible error in the correction factor, it is the variation in friction that we have in mind. Our remarks on the retardation period are based on the results of tests. We are glad to hear that Captain Law has found that the anemometer gave good results. The effect of change in friction due to temperature variation should not be appreciable, because at the velocities in question the correction for friction is small. We have not found that a deflection instrument, as advocated by Mr. Atkinson, was suitable for our purpose because of the vibrations resulting from air pulsations; while damping made the instrument insensitive. With regard to Mr. Orsettich's suggestion, it is likely that readings at intake and exhaust would increase rather than decrease labour, since a single reading at each place would not be sufficient. Further, it is often inconvenient to take anemometer readings at the

inlet. In reply to Mr. Jakeman's criticism, we would say that so long as its value is known, the actual error in the anemometer is unimportant. With reference to the remark by Dr. Kahn and others, it should be stated that the anemometer is attached to the end of a stick, so that the flow of air is not sensibly affected.

*Energy in exhaust air.*—Messrs. Law, Kaula, and Stubbs inquired if this item was important. In reply we may say that in a particular 5,000-kw. machine we calculated this loss from the test results and found it to be less than 1 kw.

*Resistance grids.*—For calibrating the air passing through the machine Captain Law and Mr. Chapman spoke of the use of resistances in which a known amount of energy was dissipated. Though in principle there is no objection to this method, which enables us to dispense with the driving-motor tests, yet the complication and possible sources of error were such that we did not feel justified in putting it forward as a standard method.

*Duration of test.*—Professor Howe and Mr. Stubbs spoke of the time taken to carry out the tests. Of course, steady conditions must obtain when readings are taken, but by suitably overloading, etc., for short periods, the duration of the tests need not be excessive (in this connection, reference may be made to Fig. C in Captain Law's remarks). Even if the time required were considerable, we do not think that this would be a serious matter in view of the importance and value of the units in question.

In reply to the further points raised by several speakers, Professor Howe is correct is assuming that in the tests on the 5,000 kw. machine referred to on page 294 the current was the full-load current in both cases; and also that 29·92 inches represents 760 mm. We are much obliged to Captain Law for his valuable contribution. The ingenious device shown in Fig. A should prove very useful. Running the alternator as a synchronous motor renders it possible for all the tests to be taken on site. We think that Major Taylor has misunderstood the title of our paper. The term "turbo-alternator" is used in the commonly accepted sense and means "turbine-driven alternator." The discussion of the turbine losses therefore falls outside the scope of the paper. With regard to Mr. Paterson's remark about heat flowing from the alternator into the base plate, and to Mr. Chapman's test proving the contrary, obviously everything depends on the conditions. From the figure given in the paper, however, it will be seen that the amount of heat associated with the whole surface of the frame is very small. We regret that Professor MacGregor-Morris did not give more details with respect to his suggestions for improving the uniformity of the air flow, also to a device for measuring the difference of temperature between the inlet and outlet air, and to an instrument for measuring mass flow. We note that Mr. Stubbs agrees that thermodynamic methods are logical and scientific, but precautions are necessary to avoid error. It is shown, however, that those precautions are simple and practicable. The calibrated air-temperature method would in general be used only where the air-heating method could not be adopted. The windage loss is included in the mechanical losses (measured with rotor unexcited). We thank him for his useful remarks on retardation tests. Mr. Orsettich strongly emphasized the need of a correct method of testing turbo-alternators. For tests at works, the calibrated air-temperature method is both practicable and reliable, and should certainly be sufficient for preliminary acceptance tests. Mr. Moffett's suggestion for circulating and cooling the same air has already been proposed but not, to our knowledge, tried. It is doubtful whether any of the gases mentioned could be used. Regarding liquids, water has been used for cooling rotors, but there are objections to having water near the machine. The use of spray in the air would provide a good cooling medium, but might be risky. In reply to Mr. Jakeman, we would point out that the paper is not intended for use in design but in the testing of machines. We agree that circumstances might arise which would entail a correction in the temperature of the inlet air. To run the alternator under test as a synchronous motor is often more troublesome than to use a driving motor, because of power supply, transformers, synchronizing, etc. Mr. Peake's suggestion for finding the losses would probably lead to inaccuracies, owing to the difficulty in measuring small differences in steam consumption.

# DISCUSSION ON

## "THE FUNCTIONS OF THE ENGINEER: HIS EDUCATION AND TRAINING."*

WESTERN CENTRE, AT CARDIFF, 27 JANUARY, 1919.

**Mr. H. I. Rogers**: I am quite in sympathy with the author's suggestions regarding commercial training in college. In my own experience, on leaving college after my three years' course I had not the slightest idea in regard to commercial matters. Nevertheless, I found myself almost at once on the business side of the industry, in connection with contract work. The need of commercial training began immediately to be felt. On taking up manufacturing on my own account the little commercial experience I had gained proved of enormous value to me. As a general rule, no one knew on leaving college whether he would stay in the high technical branches of the industry or profession, or whether he would get into distribution work where such highly technical qualifications were unnecessary. From the paper, however, it really does seem as though one is getting in 90 cases out of 100 rather an unnecessary dose of technical training, the value of which later on is comparatively slight. The idea of education is presumably to enable one to apply in practical matters what one has learnt, and I do not think the small amount of time suggested by the author could possibly reduce the value of anyone as regards his technical abilities. I feel that the paper is of such great value that a proposal such as that outlined in the author's "Conclusion" should be adopted generally by engineers.

**Mr. W. A. Chamen**: While listening to the paper, the careers of three men in particular have come across my mind. The name of one of them I can mention as he has long since departed this life. I refer to Mr. Gooch, the designer of the old broad-gauge Great Western locomotives that used to run all the express trains on that railway. He left the Great Western Railway and went to America, but in due time he returned and became Chairman of the Great Western Railway as Sir Daniel Gooch. This is one of the comparatively few instances of a real engineer rising to the top position. Another case is that of a locomotive engineer who rose from the position of locomotive engineer to that of general manager. The third case is that of one with whom I was in close touch many years ago. I noticed while he was going through his training that the greater part of his time seemed to be spent in the office. The electrical manufacturing concern with which the engineer in question and myself were both at that time connected seemed to want a certain number of pupils to assist in the office work. My friend after spending a time in the shops went into the office, but of course his duties kept him in close touch with the works also. It seemed to me that when he came out he would find a difficulty in getting on for want of a greater amount of technical practical experience, but this did not prove to be so at all. He rose to a very good position and has always been successful. He certainly has proved himself to be a good administrator. Now one of the things that must be so disappointing to engineers in general, and particularly to electrical engineers, is that in nearly every case the men who get to the top are the commercial men and not the engineers. I think the author has shown in the paper why this is so; and not only that, but he has shown that it ought not to be so, and need not be so at all. I think the remedy which he suggests is the right one, and that the reasons given for this disappointment in the past are correct. I hope that what has been said will sink deeply into the minds of those here present and be made use of, by all who have the power to do so, to improve the position and status of the engineer, and particularly of the electrical engineer.

**Professor J. Wertheimer**: I agree very largely with what the author has said, and I hope it is to be communicated not only to electrical engineers, but to the Engineering Training Organization, which represents not only all the various kinds of engineers in the country, professional and manufacturing, but also universities and technical colleges. I am very much impressed by what has been said about the necessity for business training. I remember one very distinguished engineer who, before the war, was doing poorly; he was a man of wonderful ability in designing machinery and in inventiveness, but once he made his invention, he had no further interest in it and no commercial ability. Fortunately, however, he had a son who had the kind of knowledge and training referred to by the author and a fair knowledge of engineering. The son matured about the time the war began, and they have made a great fortune and have been of very great service to the country because his invention had a large share in winning the war. So far as the University of Bristol is concerned, we have to some extent anticipated the author's proposal, for we have a course in connection with our Faculty in what we call Engineering and Manufacturing Accounts; unfortunately, however, the work is not part of the ordinary course and is not compulsory.* I should like to add that we give to that class 52 hours and we do not think it a single minute too much. The defects of university courses are not entirely due to the professors; they are, I think, due very largely to the engineers themselves, and I should like to explain why. In the first place, engineering employers in England have hitherto wanted trained men at much too early an age. In England it is possible for a boy to start the engineering course in a university at 16; I do not mean to say many begin so young as this, but a number start at 17. In the United States and in Germany no one can start an engineering course until he is 18: he must have had a thoroughly good secondary education. While the normal course

* Paper by Lieut.-Colonel W. A. J. O'Meara (see page 225).

* Next session the course will be extended and will be made compulsory.

in the British universities extends over three years, that in the United States and Germany extends over four, and engineers in these two countries are willing to take a young engineer into their works at the age of 22 or more. This is an enormous difference, and when the author speaks of the United States, it should be borne in mind that they start there with a better general education and a more complete preliminary knowledge of mathematics and the sciences underlying engineering. The main point on which I disagree with the author is that he proposes to give too little time to the commercial and administrative subjects. He talks of teaching the elements of accounts, etc., in eight hours; this involves far more time, and one can afford to give it. Another difficulty is the premium apprentice system, which, I am glad to see, is disappearing. We have tried at the University of Bristol a special sandwich scheme, which requires the student to come to us for a year and get a preliminary knowledge of engineering, and then to go into a works for a whole year, coming back to the University for two years, and then returning to the works for a fifth year. At the end of the five years, he ought to be in a position to earn a good living. When we started this system, some people thought it would be a failure, and a waste of time; I am very glad to say that 27 of the largest engineering firms in the United Kingdom have agreed to take men under this scheme, and it promises to be a very great success. Some of the most important firms take these men, and they not only do not require a premium, but they pay them a small salary for the second year, more in the fifth, and a considerable remuneration at the end of the period. The premium system secures men with cash but not necessarily men with brains. We should be careful not to introduce too much into our courses; I am not quite sure whether the whole of the author's scheme is desirable, but a great deal of it is. I am glad to hear the author speak about the necessity for a knowledge of foreign languages. I am afraid that if I were to cross-examine the engineers present I should perhaps find few who can read French rapidly, and probably still fewer who can read German. Some people would say: Leave out German; but I do not agree; the Germans pick our brains and we must get what we can out of theirs. Every engineer ought to be taught both French and German—not literary French and German or grammatical niceties—but he ought to be able to render rapidly into English, with the aid of a dictionary, the sense of a French or German engineering publication. This is of very great value, and does not take much time; at our University it is compulsory. There are financial difficulties in the way of the adoption of the scheme put forward by the author. Though the Minister of Education has given recently substantial assistance to secondary and elementary education, no additional grant has been made for university education. This condition of things will have to improve to an enormous extent for education here to be anything like what it is in the United States and Germany. The amount of money given by the State to Berlin University alone is very nearly as big as the total sum of money which the British Government gives to all our universities taken together. In America the contrast is still more marked. Why is this? In the first place, in Parliament there are very few men who have any special knowledge of science, and few who care about it. In the second place, our civil servants—and especially the first-class clerks who develop into heads of departments—have all hitherto been chosen mainly for their knowledge of classics; and nearly all the chief permanent officials of the Board of Education are literary men—even those who control technical education.

**Principal C. Coles**: I heartily agree with the author that the basis of education of the engineer, as also that of other professions, must be broad. The whole scheme must be broad, to include administrative training, to include commercial training, and also, I think, to include knowledge of social science, because, in these days when strikes and unrest are bound to come, it seems that the engineer must, like the business man, know all about social science so as to deal with these matters at first hand. I am delighted to see so strong a plea put forward for broadening the whole basis of education of the engineer. This is particularly necessary, because I think the whole question of education in this country in future will depend very largely on the relationship which can be brought about between employers and schools and colleges. Hitherto there has been too great a divorce between the two. I think that largely in the past there have been two reasons why the engineer has gone out from his college training at an extremely small remuneration. One reason is that the employer himself knows very little about the course of training undergone by the graduate, and the other is that the training of the engineer has really been so technical in character and so limited in outlook and scope that he has become more or less a bookworm and goes out into the world not sufficiently trained in breadth of outlook to be appreciated by his employer. The war has shown the value of the engineer and the chemist and also that business men and education people must work together. The whole education system has to be thrown into the melting-pot and it is hoped that a better system will result. I am glad to say that in South Wales it is the business men who have brought about a scheme which I think will, in its turn, cause this district to have, instead of one of the laggard systems of engineering education, one of the very finest in the whole country. The Business Committee of Technology and Research, which was initiated at Cardiff docks, prepared a report which was placed before the Royal Commission on University Education in Wales, whereby there will soon be established a substantial and intimate relationship between employers, the University College, the Cardiff Technical College, and other technical institutions in the area of South Wales and Monmouthshire. The result will, it is hoped, be that there will be plenty of funds available—and I am glad the County Councils are devoting a penny rate, augmented by the equivalent of a penny rate from the Government, which will provide a large nucleus sum to spend on technological education in the future—and we shall try to avoid overlapping of various institutions, and bring about the highest

possible degree of efficiency. So far as engineering is concerned, I am glad to say we in the Cardiff Technical College are bringing about a joint scheme with the University College of South Wales and Monmouthshire, in which the whole question of engineering education will be taken up vigorously. There will be no competition between the two institutions. Electrical and civil engineering will be taught at the University College, mechanical engineering at the Technical College and at the University College; while at the Technical College, marine, motor and aero engineering will receive specialized treatment, so that any person in this district will have the opportunity—whatever branch of engineering he takes up, of rising to the top in that particular branch. We have recently set apart 30 scholarships of £40 each, which will be held between the two institutions, so that we hope, so far as the full-time education of these young people is concerned, to get the full co-operation of employers through the proposed Faculty of Technology of the University. Part-time education of the engineer, under which his studies are conducted in the spare evening hours following the long laborious hours of the day, does not give the junior a fair opportunity. It is not right that young people should be put to this. Certainly men have come successfully through this very inadequate system in the past, but it is not satisfactory, and I think we shall live to see the American co-operative system very largely adopted in this country. I hope all the employers will give the necessary help in this matter to enable young people to put in half time in the schools and half time in the works—half time at the right time. We of the Technical College are also getting co-operation with employers on behalf of those young people who later will probably become the foremen and undermanagers, at the ship-repairing yards. A very excellent system is to be introduced next year, whereby the brighter evening students, after serving three years of their apprenticeship, will proceed to the Technical College for a further two years' course, and get the whole of their wages paid during the time they are there. We have the assent of the Chairman of the Bristol Channel Repairers' Association, and if introduced it will give these boys a start at the right time to develop their talents without stint to their physical and social capabilities. It seems to me the whole question raised by the author hinges on the co-operation needed between industry on the one hand and the colleges on the other. There must be closer co-operation, and my Technical Committee and the employers and workers in this district are forming Advisory Committees for mutual help. We at the College do not know industrial conditions as we should, and the employers do not know the schools as they should. By means of these Committees we can get over this difficulty to the lasting benefit of our young people.

**Mr. J. H. Shaxby**: I heartily agree with the points in the paper and also with those raised by Principal Coles, particularly as to the study of social science. The present age leaves this rather too much to the class called "labour" and too little to the employer and organizing branches; a sympathetic study of social science would be useful in helping us through these very difficult times.

**Mr. R. MacIlroy**: It is notorious that men possessing a large amount of technical knowledge and experience are often seriously handicapped through lack of general education. Such a weakness as this is very deplorable and it is often fatal to the most promising career. Some speakers have referred to the length of time which the author suggests should be given up to administrative and kindred subjects. It seems to me also that the time is very short. I take it what is meant is that so many lectures, each of an hour in duration, could be given on these subjects, but I venture to suggest that the schedule might be revised and that a larger proportion of time might be given to the study of these very important matters. It seems to me that no more important paragraph is to be found in the paper than the following on page 234:—"it cannot be too often and too strongly impressed upon the engineering student that one of the most important qualifications needed in a modern engineer consists in a command of the English language, and a facility to give expression to his thoughts through its medium with clearness, conciseness, and completeness, in speech as well as on paper." This is a remarkable statement, but it is true and, to emphasize it, I should like to say that if the author had told us nothing more than this we might very well have come to listen to him. There is one point that seems to me might be dealt with, namely, the material available. The author has been speaking about training engineers; but we may have the most up-to-date methods of training and yet, if we have not the proper material, the results are bound to be unsatisfactory. I think it would perhaps be agreed that a very brilliant and highly educated father does not of necessity produce a brilliant son. We know that the contrary is very often the case. Sociology tells us that what I may perhaps call intensive culture tends after a time to produce a certain amount of deterioration in brain and muscle. It means, I think, that for the material we have to look to the poorer classes. It behoves us at the very outset to make our scheme, whatever it might be, of such a nature that it will provide for those people whose parents cannot afford to pay for their education. The author refers to the scheme providing for rich and poor alike, but there he leaves it, and, generally speaking, he refers to students and to pupils, students whose fees have to be paid and pupils for whom premiums have to be provided. I think we have at the very outset, before we trouble very much about the actual training, to get the proper material. We are up against this point; how are we to make use of this fresh new material, assuming it were agreed that what I have said is right, while confessing that the parents of these people cannot afford to pay fees? I venture to say that to meet this difficulty we should have to go back to some extent to the old method of apprenticeship. In the paper the author refers to apprenticeship and passes it by rather quickly. He says: "Insufficient by itself." That is a simple statement of fact. Masters have contented themselves in the past by teaching juniors

a trade and leaving it at that. What I suggest is that if we go back to apprenticeship we shall meet the case of those youths whose parents cannot pay for their education; but we shall have to take apprenticeship, not by itself, but widen it and enlarge its scope. We should have to require that the master should not only teach the apprentice his business but that he should also see that he is educated in the scientific and commercial spheres as well. With all respect to the remarks of Principal Coles and Mr. Shaxby, I think the way to success in this matter is for the masters themselves to run training colleges for apprentices. My experience of schools and colleges has been that they aim at securing results in the shape of prizes and distinctions for their students, rather than at turning out thoroughly practical men. I think that if, instead of running schools and colleges as separate undertakings and apart from the industries, we had training colleges of which the masters of industry were the directors and in which they themselves were obliged to take a personal interest, we should secure the end in view. We should thus secure proper training in the scientific and theoretical aspects of the work. And I will go further; it would of course be only the smartest apprentices who would be chosen for this special training; I should require that those selected should go on and take a degree in Arts.

**Mr. H. S. Thomas**: The last speaker's suggestions with reference to the combination of employers and educational authorities were not very comforting. What he suggests has been put into practical operation by the proposed Faculty of Technology, combining the various industries of South Wales and the University authorities, to which Principal Coles referred. I am associated with Principal Coles in that matter and support him on the question of combining commercial education and teaching with technology, because, as one is perfectly well aware, there are engineers who have a wonderful theoretical and practical knowledge of their subject, but having but little commercial knowledge could easily ruin any concern if they were given free scope. I do hope that the author's outline is not to end in talk, but that, after expressions of opinion have been given by everyone wishing to do so, a Committee of the Institution will meet similar Committees appointed by other Institutions, e.g. the Iron and Steel Institute, the Institutions of Mechanical and of Civil Engineers, and possibly the combination formed in South Wales, with a view to putting into practical operation the best scheme, utilizing the very valuable suggestions made by the author.

**Mr. J. H. Berthon**: I was interested in the remarks about the technical and the administrative portion of the education of the engineer. In my opinion one of the great points wanted in the engineer is tact. I have noticed lately a well-qualified man dealing with men and failing to make a success of the business in hand through want of tact. The engineer's failure in this case had nothing to do with technical or administrative qualities, but was simply owing to a lack of principle.

**Mr. A. Nichols Moore**: The author has taken a broad view and dealt with much of his subject at considerable length, but it is impossible to deal exhaustively with a subject of this kind in a paper of the length of that to which we have listened. The salient points at issue have been clearly set out. Those present who are occupied in any administrative position must realize how true everything is that the author has said in regard to the necessity for a thorough administrative training. In order to succeed one must have, quite apart from high technical training, a proper training in administrative and commercial work. Several speakers have alluded to the extreme shortness of the period suggested by the author in regard to this administrative and commercial training. I have no desire to anticipate his reply to the discussion, but it seems clear to me that what is meant is that by some such short course the interest of the young student would be aroused and he would have set before him, as it were, a synopsis of the course that ultimately he would require to take, a part of which it is realized he will only obtain in the school of experience. Another speaker has suggested that in this country the training of engineers is commenced rather too early and that, contrary to the practice in vogue in the States and on the Continent, the employer obtains engineers at an early age and that they are expected to have an earlier money-earning capacity. I agree that what is wanted is a longer course, but I do not agree that it should be commenced later. Young students of from 14 to 15 taking a long course finishing at 21 or 22 years of age would have a much better chance of acquiring the knowledge which is essential. Another point referred to is that engineers should have a thorough grasp of the English language; I agree with previous speakers that this is an important qualification frequently overlooked. What impressed me particularly in Germany was that at several works which I visited I found that engineers in subordinate positions had quite an excellent knowledge of the English language and that they could converse with me quite freely in my own tongue, whereas I was at a considerable disadvantage in not being able to speak or understand their language. Another point I observed was that some of the highest administrative positions—contrary to the custom of this country—were occupied by engineers. In conclusion, there is a point which hardly needs emphasizing, namely, that in this country we appear to be still dependent upon foreign engineers in some of the highest technical and administrative branches. Those present who are associated with some of our largest electrical plant manufacturing concerns will understand to what I refer.

**Professor D. Robertson** (*communicated*): I agree with the author's plea for the inclusion of commercial and economic instruction in the courses of training laid down for the engineer. For some years I have felt the desirability of it, but have been deterred from making any proposals because I did not feel able to make sufficiently definite statements of what was required or of where a suitable teacher could be obtained. The paper, with its schedule of time and details of the courses, is a very great help indeed towards overcoming the first difficulty. If one hour per week were set aside for this purpose, we should have about 30

hours during the session. If this were done for two sessions, and half the course were covered in each, all the lectures being attended by students in both the third and second years' courses, we should get 60 hours. Neither of these would very seriously interfere with the technical training at present given. Assuming for the moment that the one-session course alone is practicable, how would the author cut out the excess of six hours to bring his schedule down to the time available? Or if the two-session course were chosen, how would he divide up the work between them, remembering that half the students will commence with one session's work, and the other half—those starting their college careers in alternate years—would begin these special studies in the other one? That is, each session's work would have to be suitable for men who had not already done the other. Perhaps the greatest difficulty of all, especially in the smaller cities, would be that of obtaining a really good teacher. On the one hand, the best men would be too fully occupied with commercial work to afford the time, and on the other hand, instruction by a second-class man might prove of only doubtful value. Does the author think that a really suitable man could be obtained in most provincial cities to cover the whole of his course, or would he prefer the several sections divided between two or more men? What fee would he consider sufficient to attract the right kind of man or men? I am not acquainted with the "co-operative courses" mentioned in the paper, but I think that such a scheme would be more suitable for training craftsmen and works managers than for giving the much wider study required by the engineer. Any attempt to keep the scholastic instruction within the limits of the problems encountered in the works during the preceding week must restrict it to a very limited range, and must tend to make it of a very discursive kind. After all, the problems meeting a youth during his first few years in the shops will be more frequently those of the craftsman than of the engineer. The engineer should certainly become acquainted with these problems, but his education requires very much more. He has not merely to do what has been done before, but to plan out in new directions. One of the disadvantages suffered by our engineering industries, and especially by the electrical branch, was a lack of men with sufficient theoretical training to do such work. We had some excellent men, but far too few. Our manufacturers did not appreciate the value of a college education, with the result that they got left behind in many directions because the old rule-of-thumb man who was their ideal could not (at the time of which I am thinking) design, say, an induction motor, or a high-speed steam turbine which could be relied on not to shake itself to pieces. How many of our electrical manufacturing firms have been able to manufacture induction motors without first importing from the Continent either the designs themselves, the men to make them, or machines from which to copy them? Not a very large number, I think, amongst those who started to make them early. Even so late as the outbreak of war, what proportion of our designers of electrical machinery (I don't include draughtsmen and understudies) were of British origin? This condition of affairs must be "never again," but it will be inevitable unless we train a very much larger number of men very highly on the theoretical as well as on the practical side. We shall not get these men unless our manufacturers offer sufficient inducements to attract them away from less useful but more remunerative careers. The engineer has to work with his brain rather than with his hands. His value to the community arises not from what he himself makes but from the work performed by many others acting under his direction, which work they would not be able to accomplish by themselves without that direction. If the number so directed be large, then the engineer's reward is correspondingly great. On the other hand, the earning power of a pure craftsman, no matter how skilled he may be, is limited to the value of the work which he can himself do. This is a point which should be borne in mind by parents when deciding to put their sons into an engineering career, for a very common mistake is to suppose that a boy who is skilful with his hands should make a successful engineer irrespective of his mental attainments.

**Bt.-Lieut.-Colonel W. A. J. O'Meara** (*in reply*): The author is naturally gratified to find that his proposals receive such strong support in the West Country. He feels, however, that there may be some slight misconceptions, here and there, as to his views on the nature of the instruction proposed. The time-table in his programme represents the minimum amount of preliminary instruction which, it is thought, should be given in the elements of the subjects named, and not the maximum for a full course of instruction (see page 232). It seemed to the author that half a loaf was better than no bread. His views on this subject had been hotly contested recently, on the plea that no time was available for the kind of instruction recommended. Under these circumstances, he felt that his proposals had a better chance of being accepted if he pitched his tune in a minor key than would be the case should his recommendations have been considered extravagant. The views of the author are admirably summarized in the remarks made on this point by Mr. Moore, who has correctly appreciated the idea that was uppermost in the author's mind at the time that the latter prepared the paper. Needless to say, the author is delighted to find that there is a possibility of a greater amount of time being set aside in some centres for the instruction recommended by him than that indicated in the paper. In answer to Professor Robertson's questions on the subject of the proposed programme of instruction, the author suggests that in the case where only 30 hours may be available for the preliminary course proposed, the instruction in depreciation might be entirely eliminated and that in estimating and writing of specifications reduced by 4 hours. On the other hand, should the 60 hours mentioned be available, since the whole basis of the proposal is to give preliminary elementary instruction in as wide a range of subjects as practicable, the author is of opinion that the following programme might be substituted for the one given in the paper:—

| | No. of hours of instruction |
|---|---|
| (*a*) Accountancy and book-keeping .. .. | 16 |
| (*b*) Administration and organization .. .. | 12 |
| (*c*) Application of psychology to industry .. | 2 |
| (*d*) Commercial law .. .. .. .. | 6 |
| (*e*) Depreciation .. .. .. .. .. | 2 |
| (*f*) Estimating and writing of specifications | 16 |
| (*g*) Sociology .. .. .. .. .. | 6 |
| Total number of hours of instruction .. | 60 |

The author attaches considerable importance to instruction in sociology, and entirely concurs in the view that the study of this science should not be left entirely to the classes called "labour"; this science is certainly deserving of very close study on the part of employers and administrative officials generally.

The author's view is that it would not be possible for a single teacher to cover satisfactorily even the limited range of subjects in the table given by him (see page 232); the subjects should certainly be divided between two or more men. The question of obtaining suitable teachers in small cities is, perhaps, not an easy one. However, the fact has to be borne in mind that in callings, the members of which are by the etiquette of their profession forbidden to advertise in the commercial way, there are always many very capable and ambitious young men who desire to become known. Young men of this type often start their careers in small cities, and the author ventures to think that capable young legal practitioners and accountants could be found in most small cities ready and willing, for the sake of the prestige to be gained and the professional connections to be formed thereby, to give courses of lectures in commercial law and accountancy, probably also in the other subjects mentioned. It seems preferable, however, that instruction in administration and organization and in estimating and the writing of specifications should be given by practising engineers of experience. The question of remuneration is a somewhat more difficult one to answer. Where lectures have to be prepared for delivery on single occasions only the remuneration required might, in the provinces, range to a fee of from 3 guineas to 5 guineas per lecture, according to the standing of the lecturer and the subject. However, in cases where the same lectures can be repeated frequently, it is probable that a fee of from 1 guinea to 2 guineas per lecture would prove satisfactory in most cases.

The author recognizes that "co-operative courses" cannot be introduced universally; he has only suggested that an attempt should be made to introduce such courses in cases of engineering colleges and schools situated in the great industrial centres. The author believes that the "co-operative system" was first tried at the University of Cincinnatti, U.S.A., and he has read a report wherein the success of the system is very highly spoken of. The reason why the author advocated the system in his paper was that he felt that there was a great future for scientific management in our industries. For the purpose of pushing scientific management for all that it is worth, a certain number of men of the type of the late Mr. Frederick W. Taylor of Philadelphia are wanted in this country to-day; that is to say, men possessing not only a sound theoretical knowledge of engineering, but also a most intimate acquaintance with workshop practice gained by personal experience in the performance of mechanical work. True, training of this kind will make those who have the aptitude for such work craftsmen, but this can scarcely prove to be a disqualifying element in the personal equipment of those seeking the position of a works manager or of an administrative official, should their abilities in other directions have been suitably developed at the same time by proper education and training. The author has in his varied career come across educated men who, whilst possessing high mental gifts, were at the same time extremely clever at manipulative work.

The author fully recognizes that the technical training provided for engineers in this country cannot be of too high an order. He has, for some time past, felt that the present period of three years is insufficient in which to provide the average engineering student with all the instruction which he requires in the early days of his career; this view also appears to be held by some of those who have taken part in the discussion. Something has to be done to meet this situation, and, in this connection, sight cannot be lost of the fact that the men who require a very highly specialized knowledge of electrical or other machinery form a very small proportion of the total numbers composing the engineering profession. In the author's opinion the proper method of providing for this situation is to be found in the institution of graduate courses in technology for those possessing rare gifts and a peculiar aptitude for particular classes of highly specialized work (see page 231), and he feels that steps should be taken for the institution of such courses at all our important engineering colleges and schools.

The author is in absolute agreement with those who hold the view that our manufacturers should look exclusively to the British universities and colleges for their supply of designers and other specialists: he feels that if graduate courses were introduced, as suggested, the needs of all the manufactures could be efficiently met.

The author strongly supports Professor Wertheimer's view that every engineer should have a good working knowledge of French and German. The author possesses no special aptitude for languages, but he was, in his youth, fortunate in his advisers; consequently, under serious discouragements, he persevered in his attempts to learn German as well as French, and during a long career in the engineering profession he has often felt the advantage of the knowledge acquired, at great labour, of the two languages mentioned.

Attention has been called in the discussion to the fact that the point relating to the human "material available" has not been dealt with in the paper. The author felt that it was not possible for him to deal satisfactorily with this matter; he had to accept the existing order of things as a part of our present polity. The youths of the nation are still free to enter the calling of their choice, whether they possess any natural aptitude therefor or not. Although the young men

whose parents can afford to pay for the necessary education to prepare them for the engineering profession may, to some extent, be placed in a more advantageous position, in one way, than are those whose parents are ill provided with worldly possessions, yet it has to be borne in mind that we live in an age when large numbers of scholarships are specially provided out of the public funds to enable the sons of the poor to receive the highest education available in this country. Many of those who have been fortunate enough to win the scholarships in question have adopted the engineering profession as a career. Both classes of young men, the sons of the rich and those of the poor, have almost an equal chance of making their mark in the engineering profession and of carving out a successful career therein, provided they possess the requisite ability. Some day, when we have, what may by some be considered, the "perfect State," it is conceivable that a Ministry of Applied Psychology will constitute the most important of its Public Departments; and it may be that in that era the citizens of this country will be subject, at the hands of the Department in question, to the most rigid and continuous examination, in relation to their physical and mental capabilities, from the cradle to the grave. Should these conditions, which seem to be the ideal that some social reformers are aiming at, ever come into existence, it may be possible for the State then to decide, presumably on the reports of the officials of its Ministry of Applied Psychology, as to the career that may be most suitable for each and every particular individual, first in his youth and later in his old age. Should this much be accomplished, it does not appear necessary to tax the imagination in any serious degree to picture a world in which the lives of young and old, rich or poor, shall be ordered not in accordance with the free choice of each individual composing the society of the assumed "perfect State," but rather on the highly scientific basis of the fitness of the subject for a particular sphere of activity. Such a condition of things may eventually evolve itself peacefully; it would require a violent revolution to bring it about at the present moment. Tact, it is pointed out, is a quality that engineers should all possess. No one will question this view. According to the experience of the author, the failure of men to exercise tact more often arises from ignorance than from vice or from inherent personal defects. The cure for this state of affairs lies in suitable instruction; some provision to meet this situation is proposed in Appendix IV of the paper (see "Bases of Administration . . . the art of handling men").

Principal Cole rightly concludes that the whole question raised in the paper hinges on the close co-operation between industry on the one hand and the colleges on the other. It is indeed a most healthy sign that Advisory Committees are forming in Wales between Principal Cole's Technical Committee on the one hand and the employers and workers in the district on the other: it is by the adoption of such measures alone that the colleges will be able to learn what are the requirements of the production market, as regards the mental equipment of those who are to play the important part in the administrative and executive positions connected therewith. Finance is naturally a most important consideration in education as in everything else. Necessary reforms in the sphere of technical education can alone be carried out if sufficient funds can be made available. In view of the importance to the nation of a suitable supply of efficiently trained technical men being at all times at the command of the industries of the country, unquestionably it is the duty of the Government to see to it that adequate grants are made in aid of technical education.

Finally, it is the author's hope that his small efforts to bring about a ventilation of the very important question of the reform in the engineering courses may eventually result in profit to the industries of the country generally, and at the same time prove of benefit, in particular, to the profession in which so many years of his life have been spent.

# REPORT OF THE COUNCIL FOR PRESENTATION AT THE ANNUAL GENERAL MEETING OF 29 MAY, 1919.

At this, the Forty-seventh Annual General Meeting of The Institution of Electrical Engineers, the Council present to the members their Report for the year 1918–19.

## Membership of the Institution.

The changes in the membership since the 1st April, 1918, are shown in the following table :—

| | Hon. Mem. | Mem. | Assoc. Mem. | Grad. | Studt. | Assoc. | Total |
|---|---|---|---|---|---|---|---|
| Totals at 1 April, 1918 | 9 | 1,490 | 3,542 | 446 | 702 | 478 | 6,667 |
| Additions during the year :— | | | | | | | |
| Elected | .. | 24 | 327 | 87 | 148 | 12 | |
| Reinstated | .. | 1 | 8 | 1 | 5 | .. | |
| Transferred to | 1 | 51 | 99 | 64 | .. | 1 | |
| Total | 1 | 76 | 434 | 152 | 153 | 13 | |
| Deductions during the year :— | | | | | | | |
| Deceased | 2 | 25 | 35 | 2 | 12 | 15 | |
| Resigned | .. | 11 | 18 | 6 | 8 | 4 | |
| Lapsed (Estimated) | .. | 5 | 42 | 12 | 51 | 9 | |
| Transferred from | .. | 1 | 48 | 59 | 104 | 4 | |
| Total | 2 | 42 | 143 | 79 | 175 | 32 | |
| Net Increase | .. | .. | .. | .. | .. | .. | 356 |
| Totals at 1 April, 1919 :— | 8 | 1,524 | 3,833 | 519 | 680 | 459 | 7,023 |

The corresponding figures for the last few years were as follows :—

| | |
|---|---|
| 1912 .. .. .. | 6,537 |
| 1913 .. .. .. | 7,084 |
| 1914 .. .. .. | 7,045 |
| 1915 .. .. .. | 6,811 |
| 1916 .. .. .. | 6,676 |
| 1917 .. .. .. | 6,613 |
| 1918 .. .. .. | 6,667 |

## Honorary Member.

The Council have pleasure in recording the announcement made at the Ordinary Meeting of the 5th December last that they had elected Professor Arthur Edwin Kennelly, D.Sc., of Harvard University, Cambridge, Massachusetts, U.S.A., to be an Honorary Member of the Institution.

## Honours and Distinctions Conferred on Members.

Military distinctions arising out of the War have been awarded during the year as follows :—

| Distinction | No. of Awards |
|---|---|
| C.B. .. .. .. .. .. | 1 |
| C.M.G. .. .. .. .. .. | 3 |
| C.B.E. .. .. .. .. .. | 1 |
| O.B.E. .. .. .. .. .. | 14 |
| M.B.E. .. .. .. .. .. | 3 |
| D.S.O. .. .. .. .. .. | 7 |
| Bar to D.S.O. .. .. .. .. | 1 |
| Military Cross .. .. .. .. | 29 |
| Bar to Military Cross .. .. .. | 1 |
| Distinguished Flying Cross .. .. | 1 |
| Military Medal .. .. .. .. | 2 |
| French Decorations .. .. .. | 4 |
| Belgian Decorations .. .. .. | 2 |
| Russian Decorations .. .. .. | 1 |
| Mentioned in Despatches .. .. | 23 |
| Mentioned .. .. .. .. | 5 |

The complete lists of names have been published in the *Journal* (vol. 56, *Institution Notes*, No. 6, p. 24 ; No. 7, p. 30 ; vol. 57, *Institution Notes*, No. 9, p. 4 ; No. 12, p. 23).

The following honours have also been conferred on members :—

**Knighthood.**

T. O. Callender (Member).

**C.B.E.**

W. W. Bradfield (Associate).
W. W. Lackie (Member).
G. H. Nash (Associate Member).
S. L. Pearce (Member).
R. P. Sloan (Member).
C. H. Wordingham (Member).

**O.B.E.**

R. A. S. Boyton (Associate Member).
W. B. Burnie, D.Sc.(Eng.) (Associate).
M. B. Field (Member).
A. P. M. Fleming (Member).
F. P. Fletcher (Associate Member).
R. L. Gamlen (Member).
E. Gomersall (Associate Member).
S. S. Grant (Member).
H. A. Madge (Member).
D. Martin (Associate Member).
T. L. Miller (Member).
A. Moir (Member).
J. McL. Robb (Member).
J. C. Smail, M.B.E. (Associate).
H Walker (Member).
D. Wilson (Associate Member).
W. H. Winny (Associate Member).

**M.B.E.**

L. Andrews (Member).
G. R. Battle (Associate Member).
J. S. Beddoe (Associate Member).
H. P. Brown (Associate Member).
A. H. Foyster (Member).
E. Lack (Associate Member).
R. K. Morcom (Member).
L. G. E. Morse (Associate Member).
H. J. Quick (Associate Member).
J. C. Smail (Associate).
J. E. Williams (Member).

**Ordre de Léopold, Chevalier (Belgium).**

P. Dawson (Member).
Sir William Slingo (Member).

**Ordre de la Couronne, Chevalier (Belgium).**

W. Noble (Member).

**Order of the Nile, 3rd Class (Egypt).**

A. F. T. Atchison (Member).

## Deaths.

The Council have to deplore the death of 99 members of the Institution during the year, of whom 34 lost their lives on naval or military service.

### *Roll of Honour.*

**Killed in Action.**

| | | |
|---|---|---|
| Andrews, Captain G. L. | Royal Garrison Artillery | Member |
| Baldwin, Lieutenant H. R. | Royal Naval Division | Associate Member |
| Bellamy, Lieut. H. E. | Royal Air Force | Student |
| Clears, Sapper P. J. | Royal Engineers | Associate Member |
| Cope, Gunner E. L. N. | Royal Horse Artillery | Student |
| Downes, Lieutenant H. L. | Liverpool Regt. | Associate |
| Gillespie, Major W. | Royal Engineers | Associate Member |
| Hurlbatt, Lieut.-Col. E. S., M.C. | Lancashire Fusiliers | Associate Member |
| MacIndoe, Private G. | New Zealand Signal Section | Graduate |
| Ponter, Lieut. H. W. F. | London Regiment | Student |
| Saltren-Willett, Lieut.-Col. A. J. | Royal Garrison Artillery | Associate |
| Taylor, Lieut. A. T. | Royal Engineers | Student |
| Turner, Captain H. E. | Royal Garrison Artillery | Associate Member |
| Winkley, Lieutenant S. H. | Royal Air Force | Student |
| Young, Lieut. C. | Royal Air Force | Student |

**Died of Wounds.**

| | | |
|---|---|---|
| Powell, Captain C., M.C. | Royal Engineers | Associate Member |
| Walker, Captain R. B., M.C. | West Yorkshire Regt. | Graduate |

**Accidentally Killed.**

| | | |
|---|---|---|
| Bannister, Captain E. G. | Royal Air Force | Student |
| Hopkinson, Col. B., C.M.G., F.R.S. | Royal Air Force | Member |
| Hyde-Thomson, Lieut.-Col. D. H. | Royal Air Force | Associate Member |

**Drowned.**

| | | |
|---|---|---|
| Downey, Capt. W. E. | Royal Army Ordnance Corps | Associate Member |

**Died.**

| | | |
|---|---|---|
| Andrews, Lieut.-Com. H. G. | R.N.V.R. | Associate Member |
| Claeys, Corporal W. R. E. | Belgian Army | Student |
| Davis, Lieut. V. O. I. | Royal Engineers | Member |
| Elkins, Sapper C. A. I. | Royal Engineers | Associate Member |
| Fisher, Sub-Lieut. D. G. | R.N.V.R. | Student |
| French, 2nd Lieut. The Hon. E. F. | Royal Field Artillery | Associate Member |
| Hunstone, Major W. H. | Embarkation Staff | Associate Member |
| Laurie, Captain D. S., O.B.E. | Royal Engineers | Associate Member |
| Linay, 2nd-Class Air Mech. R. E. | Royal Air Force | Student |
| Middleton, Staff Sergt. E. J. | London Electrical Engineers, R.E. | Associate Member |
| Orchiston, G. J. | New Zealand Expeditionary Force | Graduate |
| Russell, Captain G. L. L. | Royal Engineers | Associate Member |
| Whitaker, Capt. G. | Indian Army | Associate Member |

### *Other Members Deceased.*

#### *Honorary Members.*

Foster, Prof. G. C., LL.D., D.Sc., F.R.S.
Wilde, Henry, D.Sc., D.C.L., F.R.S.

#### *Members.*

Baptista, Dr. J. N.
Blackwell, R. W.
Blakey, E.
Crookes, Sir W., O.M., F.R.S.
Crosland, J. F. L.
Davies, J. H.
Eggington, A.
Enright, J., B.Sc.
Fujioka, Dr. I., M.E.
Hasegawa, T., M.E.
Houghton, E. J.
Krogh, K. K. von.
Launchbury, F. J.
Manne, J.
Martins-Guimarães, Com. J. F.
Maycock, W. P.
Mott, H. R.
Reyrolle, A.
Tierney, J. P.
Tsuboi, M., M.E.
Walker, E. O., C.I.E.
Ward, F.
Zani, A. P.

*Associate Members.*

Adams, A. C., F.R.S.E.
Braid, H. R.
Browne, R. F.
Byford, H. T.
Coleman, H. S.
Constantine, H. R., M.Sc.
da Cunha, D. B.
Davies, T.
Greaves, E. N.
Hobson, W. F.
Lesniewski, W.
Lines, F. M.
Mahood, S. A.
Mortimore, H. L.
Orr, T. R. J.
Owtram, E. H.
Parkinson, W.
Perrott, W. D.
Pintner, W., B.Sc.
Setti, S. V.
Smout, A.
White, T. M.
Wilder, F. L.

*Associates.*

Beevor, S. F.
Callender, J. O.
Carlaw, J.
Clarke, E. R., C.B.E.
Cox, E. S.
Hibberdine, E. B.
Hill, J. T.
Kilpatrick, J. L.
McWilliam, A., M.Sc.
Pollitt, R. B.
Roberts, J., M.A., LL.B.
Staples, H. J.
Walter, A. J., K.C.
West, C.

*Graduate.*

Basu, B. N.

*Students.*

Allemande, W. H.
Randall, J. E. E.

It is with very great regret that the Council record above the death of its two senior Past Presidents, Sir William Crookes, O.M., F.R.S., and Professor G. Carey Foster, LL.D., D.Sc., F.R.S.

Sir William Crookes, who was elected a Member of the Institution in 1881, served in various capacities on the Council, from 1884 to 1886 as an Ordinary Member, from 1887 to 1890 as Vice-President, and became President in 1891.

Professor Carey Foster, elected a Member in 1871, was one of the original Members of the Institution, then the Society of Telegraph Engineers, and was made an Honorary Member in 1916. He served on the Council as an Ordinary Member from 1872 to 1873, as Vice-President from 1874 to 1880, and filled the office of President in 1881. He also served as a Trustee of the Institution from the year 1898 until his death in February last.

The Council have also to deplore the loss of another Honorary Member in Dr. Henry Wilde, D.C.L., F.R.S., who was elected in 1898. He founded the Wilde Benevolent Fund of the Institution in 1899, a sum of £1,500 being presented by him for that purpose.

The loss is also placed on record, with deep regret, of Mr. J. O. Callender, who was a Member of Council from 1916 until his death in October 1918, Mr. E. Russell Clarke (Member of Council from 1909 to 1912 and from 1913 to 1916), Mr. J. Hubert Davies (Local Honorary Secretary and Treasurer for the Transvaal since 1899), Dr. Ichisuke Fujioka (Local Honorary Secretary and Treasurer for Japan from 1892 to 1916), Mr. J. T. Hill (Member of Council in 1880), Mr. J. Manne (Local Honorary Secretary and Treasurer for Belgium since 1913), Mr. J. P. Tierney (Chairman of the Irish Centre for the present Session), and Mr. A. J. Walter, K.C. (Member of Council from 1903 to 1906).

MEETINGS.

During the past twelve months 27 Ordinary, 4 Informal, and 23 Council Meetings have been held. The usual Standing Committees have met regularly, and there have also been meetings of other Committees appointed by the Council for the consideration of special matters, the total number of Meetings and Conferences held during the year being 191, as follows —:

| | No. of Meetings |
|---|---|
| Ordinary Meetings | 27 |
| Informal Meetings | 4 |
| Council Meetings | 23 |
| Committees | |
| Benevolent Fund | 4 |
| British Electrical Proving House | 6 |
| Finance | 13 |
| General Purposes | 6 |
| Lighting and Fuel Order | 3 |
| Membership | 8 |
| Papers | 9 |
| Patent Law | 10 |
| Research (including Sub-Committees and Panels) | 23 |
| War Memorial | 4 |
| Wireless Sectional Meetings | 3 |
| Other Committees and various Conferences | 48 |
| | 191 |

The corresponding figures for the last seven years were as follows :—

| | |
|---|---|
| 1912 | 156 |
| 1913 | 138 |
| 1914 | 159 |
| 1915 | 137 |
| 1916 | 117 |
| 1917 | 148 |
| 1918 | 153 |

In addition there have been 57 meetings of Territorial Centres, viz. :—

| | |
|---|---|
| Irish | 4 |
| North-Eastern | 11 |
| North Midland | 10 |
| North-Western | 10 |
| Scottish | 9 |
| South Midland | 9 |
| Western | 4 |
| | 57 |

During the Session the President, Mr. C. H. Wordingham, visited each of the Territorial Centres except the Irish Centre, which he hopes to visit at an early date.

## Papers.

The following is a list of papers read during the Session 1918–19 :—

*Papers read at Meetings.*

| *Author.* | *Title.* |
|---|---|
| G. L. Addenbrooke, Member | "Dielectrics in electric fields" (Lecture). |
| Ll. B. Atkinson, Member. | "The dynamical theory of electric engines" (Tenth Kelvin Lecture). |
| Dr. S. F. Barclay and Dr. S. P. Smith, Associate Members. | "The determination of the efficiency of the turbo-alternator." |
| J. Bibby. | "Developments in electric iron and steel furnaces." |
| W. K. Booth. | "The Booth-Hall electric furnace." |
| R. H. Campion, Member. | Chairman's Address (North Midland Centre). |
| Dr. S. Chapman. | "Electrical phenomena occurring at high levels in the atmosphere." |
| Dr. C. Chree, F.R.S. | "Magnetic storms" (Lecture). |
| H. R. Constantine, Associate Member. | "Co-ordination of research in works and laboratories." |
| Lieut.-Col. A. G. T. Cusins, R.E. | "The development of army wireless during the war." |
| A. G. Ellis and J. L. Thompson, Associate Members. | "Large power transformers." |
| M. B. Field, Member. | "The navigational (magnetic) compass as an instrument of precision" (Lecture). |
| A. P. M. Fleming, Member. | "Planning a works research organization." |
| A. P. M. Fleming, Member. | Chairman's Address, "The human factor in industry" (North-Western Centre). |
| Major A. C. Fuller, R.E., Associate Member. | "The Fullerphone and its application to military and civil telegraphy." |
| H. A. Greaves. | "Application of electrical energy to the melting of metals." |
| P. Hunter-Brown, Associate Member. | "Carbon brushes considered in relation to the design and operation of electrical machinery." |
| R. J. Kaula, Member. | "Notes on surface condensing plants, with special reference to the requirements of large power stations." |
| E. A. Laidlaw, Member, and W. H. Grinsted, Associate Member. | "The telephone service of large cities, with special reference to London." |
| Senatore G. Marconi, G.C.V.O., LL.D., D.Sc., Member. | "The continuous-wave plant at the Carnarvon station." |
| R. G. Mercer, Member. | "Electric furnaces in the United Kingdom, 1918." |
| Major J. Erskine Murray, R.A.F., Member. | "Wireless in the Royal Air Force" (Lecture). |
| J. F. Nielson, Member. | Chairman's Address (Scottish Centre). |
| Lieut.-Col. W. A. J. O'Meara, C.M.G., Member. | "The functions of the engineer his education and training." |
| A. P. Pyne, Member. | Chairman's Address (North-Eastern Centre). |
| H. I. Rogers, Member. | Chairman's Address (Western Centre). |
| A. Sahlin. | "A new type of electric furnace." |
| V. Stobie. | "Large electric steel-melting furnaces." |
| J. P. Tierney, Member. | Chairman's Address (Irish Centre). |
| Captain L. B. Turner. | "The oscillatory valve relay: a thermionic trigger device." |
| Prof. Miles Walker, D.Sc., Member. | "The supply of single-phase power from three-phase systems." |
| R. S. Whipple, Member. | "Some notes on electrical methods of measuring body temperatures." |
| R. S. Whipple, Member. | "Some notes on the electro-cardiograph." |
| H. E. Yerbury, Member. | "The effect of air and water on materials used in engineering work." |

## Students' Sections.

Eight meetings of the Students' Section have been held in London, at which papers were read and discussed. At the opening meeting an address to the Students was delivered by Professor Ernest Wilson on "The Permeability of Faintly Magnetic Materials."

Visits were made to various works by the kind permission of the firms concerned.

The Students' Section of the North-Western Centre has held eight meetings.

The Council have decided that, in the case of Students who have served in H.M. Forces and are not qualified for Associate Membership, the period during which they can remain in the class of Students may be extended by a period equal to the length of such service.

For the purpose of providing an effective link between the Council and the Students' Section, the Council have decided, with the concurrence of the Students' Committee, to appoint a Member of Council each year to be a consultative member of the Students' Committee to attend those meetings at which his presence may be specially desired by the Committee. Mr. G. W. Partridge, Vice-President, has been appointed in this capacity by the Council for the current year.

## Kelvin Lecture.

The tenth Kelvin Lecture was delivered by Mr. Ll. B. Atkinson, Member, on the 7th November, 1918, the subject of the lecture being: "The Dynamical Theory of Electric Engines."

## Premiums.

The following premiums for papers have been awarded by the Council :—

*The Institution Premium* (*value £25*).

| | |
|---|---|
| Prof. Miles Walker, D.Sc. | "The supply of single-phase power from three-phase systems." |

*The Ayrton Premium* (*value £10*).

| | |
|---|---|
| R. S. Whipple. | "Some notes on the electro-cardiograph." |
| | "Some notes on electrical methods of measuring body temperatures." |

*The John Hopkinson Premium* (*value* £10).

| | |
|---|---|
| P. Hunter-Brown. | "Carbon brushes: considered in relation to the design and operation of electrical machinery." |

*The Kelvin Premium* (*value* £10).

| | |
|---|---|
| S. F. Barclay, Ph.D., and S. P. Smith, D.Sc. | "The determination of the efficiency of the turbo-alternator." |

*The Paris Premium* (*value* £10).

| | |
|---|---|
| R. Knox, M.D. | "Single-impulse radiography (instantaneous): its limitations and possibilities." |

*An Extra Premium* (*value* £10).

| | |
|---|---|
| E. P. Cumberbatch, M.B., B.Ch., M.R.C.P. | "Diathermy: the use of the electrical current to raise the temperature of the body in the treatment of disease." |

*An Extra Premium* (*value* £10).

| | |
|---|---|
| Lt.-Colonel W. A. J. O'Meara, C.M.G. | "The functions of the engineer: his education and training." |

### Scholarships.

In view of the absence of a large number of Students on Naval or Military Service, the Council have again made no awards of the David Hughes and the Salomons Scholarships.

### Paul Scholarship.

With the concurrence of Mr. R. W. Paul, whose generous gift of £500 for the development of methods and means for electrical measurements was recently recorded in the *Journal* (1919, vol. 57, p. 151), the Council have made the following arrangements:—

(*a*) The interest (about £25 per annum) on the £500 presented by Mr. Paul to be devoted to a Paul Scholarship for post-graduate work on the development of methods and means for electrical measurements.

(*b*) The Scholarship to be awarded to Students who have gone through a full electrotechnical course and have obtained a degree, diploma, or certificate equivalent to those accepted in lieu of the A.M.I.E.E. examination, on condition that they take up instrument-making work while holding the Scholarship.

(*c*) Applicants for the Scholarship to be invited to submit their names to their Professors, who will report on their applications to the Paul Scholarship Committee which has been appointed by the Council to make the awards.

The first award will be made this summer.

### Territorial Centres.

A Committee was appointed by the Council in March 1918 to review the position of the Local Sections and to make suggestions as regards increasing their usefulness. The Report of this Committee was duly considered by the Council and as a result it was decided:—

(*a*) That the Local Sections be known in future as "Centres," their names being altered as follows:—

| *New Name.* | *Former Name.* |
|---|---|
| North-Western Centre | Manchester Local Section |
| North Midland ,, | Yorkshire ,, ,, |
| South Midland ,, | Birmingham ,, ,, |
| North-Eastern ,, | Newcastle ,, ,, |
| Western ,, | Western ,, ,, |
| Scottish ,, | Scottish ,, ,, |
| Irish ,, | Dublin ,, ,, |

The Irish Centre to include the whole of Ireland.

(*b*) To empower the Territorial Centre Committees to represent the Institution on other bodies, such as Chambers of Commerce, Technical Library Committees, Education Authorities, kindred Engineering Societies, and so forth, subject to the approval of the Council in each case.

(*c*) To delegate certain branches of research to some of the Territorial Centres by the formation of local Research Sub-Committees; such Sub-Committees to be appointed by the Council at the instance of the Territorial Centre Committees. Each Sub-Committee to report to the Research Committee and to keep the Territorial Centre Committee informed of the progress of the particular research.

(*d*) To invite other bodies to co-operate through their local Associations in regard to forming local Engineers' Clubs.

In view of the success of the Tees-side Sub-Centre a Territorial Sub-Centre has been established at Sheffield (North Midland), and others will shortly be established at Aberdeen (Scottish), Leicester (South Midland) and Preston (North-Western), for the purpose of holding local informal meetings at regular intervals, in addition to holding each session at the Sub-Centre one or two meetings of the parent Centre.

### Western Centre.

The Council have decided to include in the Western Territorial Centre the whole of the counties of Pembroke, Radnor, Cardigan, Carmarthen, Brecknock, Gloucester, and Hereford.

### Wireless Meetings.

The Council have appointed a Committee to arrange for meetings for the reading and discussion of papers on Radio-telegraphy and High-frequency Engineering.

Wireless telegraphy has been a closed subject during the War; at the same time the progress of discovery and invention in this subject and the development of manufactures have been exceedingly rapid. The cessation of hostilities has opened up the possibility of disclosing and discussing the advances made in the subject.

The Committee met for the first time on 17th February, 1919, and have been able to arrange for four meetings to be held during the present Session.

### Informal Meetings.

The Council have made arrangements for the holding of Informal Meetings which it is hoped will enable the

younger members of the Institution to derive more benefit from it and to take a more active interest in its work. The meetings are open to members of all classes and smoking is allowed. The number of meetings arranged for this Session is four, the subjects of discussion being as follows :—

"The Future of Trade Unions as affecting the Engineering Industry." (Introduced by Mr. F. Pooley.)

"Electrical Instruments." (Introduced by Dr. R. D. Gifford.)

"The Regulations issued by Electricity Supply Undertakings." (Introduced by Mr. W. E. Bradshaw.)

"The Vicious Circle of Increasing Prices." (Introduced by Mr. K. Edgcumbe.)

At the two meetings which have already been held, the attendances and discussions were very satisfactory. A number of senior members of the Institution have attended the meetings, and their informal contributions to the discussions have been an encouragement to the junior members. The Council believe that information, useful to all members, will be obtained from the expression of the views of younger members actually engaged in executive work.

### Discussions on Wiring and Installation Work.

With the co-operation of the Electrical Contractors' Association and the Association of Supervising Electricians, the Council are making arrangements for discussions on subjects of interest to wiring contractors and their assistants. The first meeting for this purpose will be held in May.

### Associate Membership Examination.

In view of the practical impossibility until more normal conditions are reached of holding the Associate Membership Examination and of candidates having the requisite time to prepare for or undergo examination, the Council have suspended temporarily the Institution rules in regard to examinations. The greatest care will nevertheless be exercised by the Council to ensure that only candidates possessing the qualifications laid down in the Articles in respect of training and experience are admitted to Associate Membership.

### Members on Naval or Military Service.

From returns supplied by members it appears that the number of members serving or having served in the Navy or the Army since the outbreak of the War is 2,021, namely, 181 Members, 930 Associate Members, 88 Associates, 170 Graduates, and 652 Students.

A Greetings Card was again sent last Christmas in the name of the Institution to its members on active service.

The Council have under consideration arrangements for welcoming in a suitable manner this summer members who have been engaged on Naval or Military Service during the War.

### Demobilization.

At the request of the Ministry of Labour (Demobilization and Resettlement Department) the President became a member of the Committee of the three Institutions of Civil, Mechanical, and Electrical Engineers appointed to assist the Department by acting as a central authority to select men whose immediate return to civil life was most necessary from the point of view of resettlement and the restarting of industry.

The Council also nominated Mr. W. Judd to be a member of the Demobilization Advisory Boards which proceeded to the Continent to advise officers and men in regard to civil careers on demobilization.

### Electric Power Supply in France.

In response to an invitation from the Army Council asking the Council to nominate a representative to serve on the Commission appointed by the Army Council to inspect and report upon the Electric Power Supply arrangements in the war areas in France and to report on future policy in regard to such matters, the Council appointed the President, Mr. C. H. Wordingham, for this purpose. The Commission spent 10 days in France examining witnesses and inspecting various establishments and sites and presented a lengthy Report.

### Corps of Royal Engineers.

The Council have also nominated the President, at the request of the Army Council, to give evidence before a Committee appointed by the Army Council to report upon the future functions and organizations of the Corps of Royal Engineers, presided over by Sir Henry Rawlinson, Bart., G.C.B., G.C.V.O., K.C.M.G.

### War Memorial to Fallen Members.

In January last a circular was issued to all members, inviting subscriptions to a Fund for the assistance of wounded and disabled members and their dependents, and the dependents of members who had lost their lives in the War. It is proposed also to set up in the Institution building a permanent record in the form of a bronze tablet commemorating the names, regiments, etc., of the fallen members.

### Electrical Appointments Board.

The Electrical Appointments Board, which in order to comply with legal requirements is an organization separate from the Institution, has been set up with the object of acting as intermediary between employers and members seeking employment.

Owing to the limited number of vacancies reported, the Board have decided that for the present only members who have served in H.M. Forces can be dealt with. The number under this heading whose names are at present on the register is 230. 171 members have been communicated with in connection with 35 vacancies which have, up to the present, been reported to the Board.

The Board desire to impress upon all employers the strong claims of these members in regard to priority of employment, and they will be glad to receive particulars of vacancies in the Electrical Industry. On receipt of particulars the Board will submit to the employer the names of applicants possessing suitable qualifications.

Communications should be addressed to The Secretary, The Electrical Appointments Board, 1, Albemarle-street, W. 1.

### Local Honorary Secretary and Treasurer Abroad.

The Council have appointed Mr. W. Elsdon Dew to be Local Honorary Secretary and Treasurer of the Institution for the Transvaal, in succession to the late Mr. J. H. Davies.

### Wiring Rules.

Since the last Report, the revision of Rules 68 and 69, dealing with lead-covered conductors, has been completed, and the amended Rules 68 and 69 were issued last July, together with certain other corrections, in the form of an "Alterations" slip, which is now inserted inside the front cover of all copies of the Seventh Edition of the Rules.

### Regulations for the Electrical Equipment of Ships.

The draft of the proposed Regulations has been completed by the Ship Electrical Equipment Committee and page proofs will shortly be submitted to the Council for approval. It is proposed to publish the Regulations in pocket-book size with alternative bindings.

The preliminary draft of the Regulations was discussed last year at meetings of the North-Eastern and Scottish Centres and a number of suggestions were made by members. These suggestions have been fully considered in detail by the Committee and embodied, where desirable, in the Regulations.

The Council have good reason to believe that the Regulations, when issued, will be generally adopted, and it may be mentioned as evidence of this and the need felt for Regulations of the kind, that several shipping companies and ship-building firms have applied for the preliminary draft of the Regulations and are employing them.

In connection with the Regulations, the British Engineering Standards Association have undertaken, at the request of the Committee, the preparation of Standard Specifications for various apparatus to meet the requirements set forth, and these Specifications, which are referred to in the Regulations, will be issued about the same time as the latter.

### "Science Abstracts."

Although the size of the volumes of "Science Abstracts" for 1918 had to be reduced owing to the paper restrictions, the cost of the publication increased again, on account of further rises in the cost of paper and printing. The net cost to the Institution for 1918 was £807, as compared with £513 in 1917.

### Model General Conditions for Contracts.

The Council have decided upon the following alteration to Clause 24: In the case of Contracts made on and after the 1st January, 1919, the amounts of the instalments of the retention money specified in Clause 24 (2) will be altered from 10 per cent and 10 per cent to 15 per cent and 5 per cent respectively.

### Research.

#### *The Electrical Research Committee.*

The Councils of the Institution and of the B.E.A.M.A. have decided that in future, subject to mutual agreement between them in each case, all researches initiated by either the Institution or the Association whether State aided or not shall be handled by the Electrical Research Committee. This Committee will hold and administer the funds, make arrangements for the conduct of the researches and follow up the work, rendering all necessary assistance to the research workers to ensure the progress of the investigations.

The Committee, which now consists of 14 members, of whom 7 are appointed by the Institution and 7 by the Association, have appointed Mr. E. B. Wedmore as Director of Research to organize and supervise this work.

#### *Insulating Materials Research.*

Some progress has been made during the year with the Joint Research by the Institution and the B.E.A.M.A. on Insulating Materials, but the work has been considerably delayed by the difficulty of obtaining steel moulds and, consequently, test specimens. Provisional specifications have been drafted for Hard Composite Dielectrics (which include Ebonite), Untreated Insulating Papers, and Mica, and progress has been made with the drafting of a specification for Porcelain. These researches have now been transferred to the Electrical Research Committee.

#### *Buried Cables Research.*

Further progress has been made with this research, but results are not yet available for publication. The amount expended on the research in 1918 was £118, of which £45 10s. was contributed by the Institution, the remainder being defrayed out of the balance in hand from grants for previous years from the Research Department.

In addition to this expenditure, the National Physical Laboratory has carried out for the Institution, at the expense of the Research Department, work which cost a further £465.

#### *Insulating Oils Research.*

A first report from the investigators having been received, a Panel was appointed to examine these reports and present a critical summary to the Research Committee. After consideration of the reports, the Panel was of opinion that it would be advisable to clear up some discrepancies in the reports and to carry out certain additional work before presenting a report to the Committee. This work has now been practically completed and it is expected that a full report of the

work of the Committee will shortly be ready. In addition to the work mentioned in last year's report, work has been carried out on dielectric strength and specific heat

### Engineering Training Organization.

The Council sanctioned last year a contribution of £250 towards the expenses of the above Organization.

### Patent Law Amendment.

The Report of the Patent Law Committee was adopted by the Council in June last and has been published in the *Journal* (1919, vol. 57, p. 64). The Report was also adopted, subject to a few verbal alterations, by a Conference of representatives of some 30 leading scientific and technical Societies, convened by the Institution of Mechanical Engineers. A deputation from the Conference waited on the President of the Board of Trade on the 10th October, when the Report formed the basis of the representations made to the Board by the deputation.

### Fuel and Lighting Order, 1918.

A deputation consisting of representatives of the Institution, the various Electricity Supply Associations, the B.E.A.M.A. and others, was twice received in May and June last by the Deputy Coal Controller in connection with the proposed Fuel and Lighting Order. As a result satisfactory modifications were embodied in the Order.

### Military Service Act, 1918.

The Council were in communication during 1918 with the Ministry of National Service with reference to the utilization, with due regard to their skill, of members of the Institution called up for military service under the above Act.

With a view to members of the new military age being posted, as far as vacancies were available, to technical units on being called up for military service, arrangements were made by the Council with the Ministry for such members to be supplied with the Form and Certificate approved by the Ministry for this purpose.

### Overhead Power Lines.

The Council have appointed a Committee to consider and report on Regulations for overhead power lines, excluding tramway working conductors.

The hampering of the extension of high-pressure transmission and low-pressure distribution by unnecessary cost, and the better securing of the safety of the public by cheaper methods of construction will be specially considered by the Committee.

On the initiative of the President the British Engineering Standards Association has also taken up the question of standardizing such items of Overhead Line Construction as may be found expedient and, through the International Electrotechnical Commission, the setting up of international standards for aluminium. This work will proceed hand in hand with that of the Institution.

### Technical Co-operation.

The Council have set up a Committee for the purpose of securing technical co-operation between this country and the Dominions and Colonies and foreign countries. The objects of the Committee are :—

(*a*) The interchange of technical experience and practice in connection with Safety Rules. Wiring Rules (installation and use of plant, as distinct from standardization thereof), etc.

(*b*) The exchange of inquiries as to engineering practice, etc., and their transmission to the appropriate Committees.

The Council are confident that the exchange of views and experience which will result from the work of the Committee will be of the greatest value to British electrical engineers and will tend to bring together in friendly relationship the electrical engineers of the allied nations.

### Inventions, Research and Experiments.

At the request of the Admiralty, a Committee of the Institution was formed last May to assist the Authorities in connection with War Inventions, Research and Experiments.

The Committee appointed an Executive Section which held a number of meetings. The functions of the Committee came to an end at the conclusion of hostilities.

### National Electrical Proving House.

The Committee of representatives of various interested Bodies, appointed by the Council to consider the question of an Electrical Proving House, have prepared a detailed scheme. The matter is under consideration by the parties concerned.

### Electric Power Supply.

A letter addressed to the Board of Trade on the 1st January, 1919, by a Committee consisting of representatives of the Institution and other interested bodies, in regard to the Report of the Board of Trade Committee on Electric Power Supply, was published in "Institution Notes" in the *Journal* for January last. The letter was approved by the Council at a meeting held on the 9th January, 1919.

The Council have since addressed a letter to the Prime Minister urging that the question of placing Electricity under the Ministry proposed to be set up under the Ways and Communications Bill should not be finally settled until the forthcoming Supply of Electricity Bill is published and there has been an opportunity for its details to be considered. The Council are glad to note that an announcement has been made to the effect that without prejudice to its possible reinstatement the Clause relating to Electricity has been struck out of the Bill. A special Committee

has been appointed by the Council to formulate a plan to obtain the opinion of members of the Institution on the Supply of Electricity Bill when published.

### Maintenance Agreement for Secondary Batteries.

The Committee appointed by the Council last year to prepare a standard Maintenance Agreement for Batteries requested the representatives of the B.E.A.M.A. on the Committee to place the matter before the Accumulator Makers' Section of the Association. This action was taken, but owing to the illness of one of the two members of the Section to whom the matter was referred, the draft agreement is not yet ready for discussion by the Committee.

### Electrical Power Engineers' Association.

Early in 1918 representations were made to the Council that the formation of a Protective Association for British Electrical Engineers was most desirable, and that in the event of such an Association being formed arrangements could be made for existing Bodies with similar objects to be merged into it. Meetings were accordingly held in London and at the Territorial Centres from which it appeared that one of the existing Associations could be selected instead of setting up a new Association. Subsequently a Conference was held of representatives of the Associated Municipal Electrical Engineers of Greater London, the chief Technical Assistants' Association, and the Electrical Power Engineers' Association, at which it was decided :—

(1) That one single combined protective Association be formed for the whole electric supply industry.

(2) That Chief Engineers be included in the membership provided they are not employers or employers' representatives on an Industrial Council or similar body dealing with technical staffs, subject also to proper safeguards for special staff questions that may arise.

(3) That a protective Association formed from existing associations adopt the constitution, and for the present the title, of the Electrical Power Engineers' Association, seeing that it is the only existing Association for the purposes in view which is constituted as a Trade Union.

(4) That the qualifications for membership of the Association be those of the Electrical Power Engineers' Association, but all new members elected after 31st December, 1921, shall be required to have passed the A.M.I.E.E. Examination or an equivalent examination, and that this be the link between the Institution and the Association.

The President attended a meeting of the National Executive Committee of the Electrical Power Engineers' Association at Manchester on the 27th July last, and in October the Council decided to recognize officially the Electrical Power Engineers' Association as the protective Association for Engineers qualified to hold a responsible position directly concerned with the production, transmission, distribution, or utilization of electrical energy.

### Electrical Development Association.

The Council appointed in 1918 a Committee, consisting of representatives nominated by interested bodies, to prepare a scheme for electrical development. As a result, there has been formed a new body, under the above title and as a separate organization independent of any Institution or Association.

The objects of the Association are to educate the public in the widest possible use of electricity in all branches of the industry, and to collect, co-ordinate, and distribute data of interest to members of the Association.

The Association will work through its Executive Committee which will be composed of representatives of Institutions and Associations and others identified with any branch of the Electrical Industry.

Members of the Association will consist only of those interested in the manufacture of electrical plant or apparatus, Supply Authorities, and Installation Contractors.

The Council of the Association have appointed Mr. J W. Beauchamp as Director.

### Proposed Society of Radiographers.

A preliminary Committee is engaged in drawing up a draft Memorandum and Articles of Association for a proposed Society of Radiographers, whose principal objects will be to ensure that only adequately trained radiographers are employed in electro-medical work, and to promote the science and practice of Radiography. The Committee consists of four members nominated by the Institution, four nominated by the British Association of Radiologists and Physiotherapists, and four Radiographers.

### The Institution Building.

The work of the Institution continues to be seriously handicapped through the occupation of the Institution building by the Authorities. The Council have urged upon H.M. Office of Works the importance of the Institution being reinstated at the earliest possible date, but the Department are unable yet to state definitely when the building will be handed back.

### Library and Museum.

Owing to the continued retention of the Institution Building by H.M. Office of Works, the bulk of the Institution Reference Library, the entire Ronalds' Library, and the collection of historic apparatus in the possession of the Institution are still inaccessible to members.

By kind courtesy of the Council of the Institution of Civil Engineers, the Library and Reading Rooms of that Institution continue to be at the disposal of members. The Library and Reading Rooms are open on week-days from 9.30 a.m. to 5.30 p.m. excepting on Saturdays, when they are closed at 1 p.m.

The Council wish to remind members that the Lending Library is available to those who wish to borrow books

Copies of the catalogue may be had on application to the Secretary. During the year, 497 books were issued to 205 borrowers, the corresponding numbers in the previous year being 354 and 191 respectively.

It is hoped that during the next year or two there will be additions to the Museum of apparatus of interest in connection with the War. Members possessing or able to obtain such apparatus are invited to communicate with the Secretary.

It may be of interest to members to know that the idea of forming a collection of old electrical instruments and papers originated about 12 years ago with Mr. Killingworth Hedges. Sir John Gavey and others took an active interest in the matter in its early stages and the late Mr. Duddell carried on the work with great enthusiasm. A classification of the objects in the Museum which was in progress when war broke out has necessarily been suspended, but it will be resumed when conditions are again normal.

## Benevolent Fund.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1918, the Capital Account of the Fund stood at £5,709 9s. 6d. and the accumulated Income at £1,248 19s. 9d. The donations and subscriptions to the Fund in 1918 amounted to £259 3s. 10d.

In the course of the year 19 grants were made, amounting to a total of £229 15s.

The response from members to the recent appeal for subscriptions to the above Fund has been most gratifying to the Committee. The following is a comparison of the number of subscriptions and the amounts received up to the 15th April during the present year and for the same period a year ago:—

| | Number of Subscribers | Amount Subscribed |
|---|---|---|
| 1919 | | |
| 1 January to 15 April .. | 570 | £422 0s. 6d. |
| 1918 | | |
| 1 January to 15 April .. | 104 | £133 6s. 0d. |

The Accounts of the Fund, which are separate from those of the Institution, will be found on page 337 of volume 57 of the *Journal*.

## Annual Accounts.

*Excess of Income over Expenditure.*—After making full provision for contingencies there is a margin to the good on the Revenue Account for 1918 of £1,270 11s. 5d. This amount, which has been carried to the credit of the General Fund, compares with £2,089 18s. 11d. in 1917, a decrease of £819 7s. 6d.

*Mortgages.*—

| | £ | s. | d. |
|---|---|---|---|
| In the Accounts for 1917 these stood at | 31,914 | 0 | 0 |
| Amount of repayment during the year | 839 | 16 | 7 |
| They now stand at .. .. .. | £31,074 | 3 | 5 |

*Life Compositions Fund.*—The total of the Fund on the 1st January, 1918, was £5,283 9s., and a further amount of £44 2s. was received in payment of Life Compositions during the year, a total of £5,327 11s. Out of this the sum of £125 8s. has been transferred to the General Fund, in accordance with the Articles of Association, on account of Life Compositions of members deceased during the year, leaving to the credit of the Fund £5,202 3s.

*Building Fund.*—This has been augmented during the year by—

| | £ | s. | d. |
|---|---|---|---|
| Donations, Subscriptions, etc. .. .. | 79 | 8 | 6 |
| Contribution out of Institution Revenue .. | 760 | 8 | 1 |
| | £839 | 16 | 7 |

which amount was applied in reduction of the Economic Life Assurance Society's mortgage, as shown above.

*Assets.*—Taking the Tothill-street Property and the Investments at cost, and the Institution Building and Lease, the Library and Furniture, etc., at the values standing in the books after writing off depreciation—

| | £ | s. | d. |
|---|---|---|---|
| the Assets amount to .. .. .. | 134,674 | 13 | 7 |
| against Liabilities .. .. .. | 42,925 | 11 | 4 |
| leaving a balance to the good of .. | £91,749 | 2 | 3 |

which is made up as follows:—

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Building Fund .. | 46,362 | 18 | 5 | | | |
| Life Compositions Fund | 5,202 | 3 | 0 | | | |
| Kelvin Lecture Fund | 648 | 13 | 0 | | | |
| Foreign Visit Fund .. | 92 | 14 | 2 | | | |
| Reserve Fund .. | 8,000 | 0 | 0 | | | |
| General Fund .. | 31,442 | 13 | 8 | | | |
| | | | | 91,749 | 2 | 3 |
| This balance, in comparison with that of 1917 of .. .. .. | | | | 84,780 | 5 | 1 |
| shows an improvement for 1918 of .. | | | | £6,968 | 17 | 2 |

## War Loan.

Since the accounts for 1918 were closed, a further £7,000 5% National War Bonds has been purchased by the Institution.

# THE INSTITUTION OF ELECTRICAL ENGINEERS.

## REVENUE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1918.

**Dr.** EXPENDITURE.

| Year ended 31 Dec., 1917. | | £ s. d. | £ s. d. |
|---|---|---|---|
| £ s. d. | | | |
| | To MANAGEMENT :— | | |
| | Salaries and Wages (including Staff Provident Scheme and War Bonus) ... | 4,553 8 1 | |
| | National Insurance ... ... ... ... | 7 7 0 | |
| | Accountants' Fees ... ... ... ... | 31 10 0 | |
| | Printing ... ... ... ... ... | 293 16 8 | |
| | Stationery and Office Requisites ... ... | 577 5 0 | |
| | Addressing Machine Plates ... ... | 14 9 10 | |
| | Postage of Correspondence and Notices | 224 4 6 | |
| | Telephone ... ... ... ... ... | 47 15 8 | |
| | Travelling Expenses ... ... ... | 37 2 5 | |
| | Bank Charges ... ... ... ... | 10 0 7 | |
| 4,805 11 2 | | | 5,796 19 9 |
| | „ INSTITUTION BUILDING :— | | |
| | Ground Rent ... ... ... ... | 2,201 0 0 | |
| | Rates and Taxes ... ... ... ... | 561 8 5 | |
| | Insurance ... ... ... ... ... | 92 18 11 | |
| | Reserve for Repairs ... ... ... | 400 0 0 | |
| 3,669 15 9 | | | 3,255 7 4 |
| 813 0 7 | „ TEMPORARY OFFICES (No. 1 Albemarle Street) :— Rent, Lighting, Heating, Cleaning, etc.... ... ... | | 1,127 17 11 |
| 1,364 19 9 | „ INTEREST ON MORTGAGES ... ... ... ... ... | | 1,369 3 11 |
| 49 18 6 | „ FURNITURE AND FITTINGS (Repairs and Renewals) ... ... ... ... ... ... ... | | 18 16 0 |
| | „ JOURNAL :— | | |
| | Printing ... ... ... ... ... | 2,100 18 5 | |
| | Postage ... ... ... ... ... | 497 9 7 | |
| | Wrappers and Envelopes ... ... ... | 246 6 11 | |
| | | 2,844 14 11 | |
| | *Less* Sales ... ... ... ... | 486 19 3 | |
| 1,367 17 6 | | | 2,357 15 8 |
| 27 16 4 | „ LENDING LIBRARY (Books, Printing, Postage, etc.) ... | | 17 10 3 |
| 22 2 10 | „ THOMPSON MEMORIAL LIBRARY :— Insurance, etc. ... ... ... ... ... ... | | 7 0 0 |
| | Carried Forward ... ... ... | | £13,950 19 10 |

**Cr.** INCOME.

| Year ended 31 Dec., 1917. | | £ s. d. | £ s. d. |
|---|---|---|---|
| £ s. d. | | | |
| 15,399 18 0 | By SUBSCRIPTIONS ... ... ... ... ... ... | | 16,344 2 2 |
| 583 5 6 | „ ENTRANCE FEES ... ... ... ... ... ... | | 1,076 15 6 |
| 67 4 0 | „ LIFE COMPOSITIONS ... ... ... ... ... ... | | 44 2 0 |
| | „ BUILDING FUND :— | | |
| | Donations and Subscriptions ... ... | 10 2 6 | |
| | Vellum Diplomas ... ... ... ... | 69 6 0 | |
| 43 2 6 | | | 79 8 6 |
| 620 1 11 | „ DIVIDENDS ON INVESTMENTS ... ... ... ... ... | | 993 13 0 |
| 112 18 3 | „ INTEREST ... ... ... ... ... ... ... ... | | 62 19 6 |
| 7 14 5 | „ WIRING RULES ... ... ... ... ... ... ... | | 8 2 2 |
| 19 5 3 | „ MODEL GENERAL CONDITIONS ... ... ... ... | | 14 13 3 |
| | „ INSTITUTION BUILDING :— | | |
| 5,086 1 5 | Rent from Tenants ... ... ... ... ... ... | | 5,865 10 0 |
| | „ TOTHILL STREET PROPERTY :— | | |
| | Rents from Tenants ... ... ... ... | 861 10 10 | |
| | *Less* Ground Rent, Repairs, Alterations, Rates, Taxes, etc. ... ... ... | 491 15 0 | |
| 175 2 9 | | | 369 15 10 |
| 22,441 17 0 | Carried Forward ... ... ... ... | | £24,859 1 11 |

# REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

| | | £ s. d. | £ s. d. |
|---|---|---|---|
| | Brought Forward ... ... ... ... | ... | ... 13,950 10 10 |
| | To NATIONAL SERVICE:— | | |
| | Honours Lists, Release of Pivotal Men, Employment, Greetings Card, Postage, etc. ... ... ... ... ... ... | 41 10 7 | |
| | Allowances to Members of Staff on Military Service ... ... ... ... | 586 3 0 | |
| *608 0 7* | | | 628 2 7 |
| | „ SCIENCE ABSTRACTS:— | | |
| | Salaries, Abstracting, Printing, Postage, etc.... ... ... ... ... ... | 2,000 11 2 | |
| | *Less* Subscriptions, Sales, and Advertisements ... ... ... ... ... | 1,192 18 4 | |
| *513 9 3* | | | 807 12 10 |
| | „ MEETINGS:— | | |
| | Advance Proofs ... ... ... ... | 64 10 0 | |
| | Reporting ... ... ... ... ... | 86 2 4 | |
| | Honoraria to Kelvin Lecturers ... ... | 50 0 0 | |
| | Refreshments, Assistance, etc. ... ... | 100 2 4 | |
| | Hire of Rooms ... ... ... ... | 96 4 6 | |
| *197 7 2* | | | 306 19 2 |
| | „ TERRITORIAL CENTRES:— | | |
| | Money Grants ... ... ... ... | 331 8 0 | |
| | Travelling Expenses ... ... ... | 377 12 5 | |
| *754 8 10* | | | 709 0 5 |
| *50 17 9* | „ PREMIUMS ... ... ... ... ... | ... ... | 115 1 10 |
| | „ SPECIAL GRANTS:— | | |
| | Engineering Training Organization ... | 250 0 0 | |
| | British Scientific Products Exhibition ... | 52 10 0 | |
| | Conjoint Board of Scientific Societies ... | 50 0 0 | |
| | British Engineering Standards Association | 50 0 0 | |
| *600 0 0* | | | 402 10 0 |
| *3 14 6* | „ SHIP WIRING RULES (Preliminary expenses) | ... ... | 15 12 6 |
| —— | „ STREET LIGHTING SPECIFICATIONS (cost of Printing, *less* Sales) ... ... ... | ... ... | 7 4 8 |
| | „ RESEARCH:— | | |
| | Buried Cables and Insulating Oils ... | 145 10 0 | |
| | Electrical Research Committee ... ... | 100 0 0 | |
| *153 1 10* | | | 245 10 0 |
| *62 19 0* | „ LEGAL EXPENSES ... ... ... ... | ... ... | 14 3 0 |
| *78 13 8* | „ MISCELLANEOUS EXPENSES ... ... ... | ... ... | 84 9 5 |
| | | | 17,376 17 3 |
| | „ AMOUNTS TRANSFERRED TO:— | | |
| *67 4 0* | LIFE COMPOSITIONS FUND (*per contra*) ... | 44 2 0 | |
| | BUILDING FUND (Obligatory repayment to Economic Life Assurance Society):— | | |
| | Donations, Subscriptions, etc. (*per contra*) ... £79 8 6 | | |
| | Contribution out of Revenue 760 8 1 | | |
| *805 4 10* | | 839 16 7 | |
| *277 12 2* | SINKING FUND (Premiums for Redemption of Cost of Building and Lease) ... | 277 12 2 | |
| *3,000 0 0* | RESERVE FUND (Contingencies and Mortgage Redemption) ... ... | 5,000 0 0 | |
| | GENERAL FUND:— | | |
| | Expenditure on— | | |
| *57 17 1* | Books and Binding for Library ... | 50 2 6 | |
| *2,089 18 11* | **Balance of Revenue for the year 1918** | 1,270 11 5 | |
| | | | 7,482 4 8 |
| | | | £24,850 1 11 |

Cr. INCOME—*continued.*

| | £ s. d. |
|---|---|
| Brought Forward ... ... ... ... ... ... | ... 24,859 1 11 |
| | £24,859 1 11 |

# BALANCE SHEET, 31ST DECEMBER, 1918.

**Dr.** LIABILITIES.

| | £ s. d. | £ s. d. |
|---|---|---|
| To Building Fund :— | | |
| Balance at 1st January, 1918 ... ... ... | 45,523 1 10 | |
| Donations, Subscriptions, etc. ... ... ... | 79 8 6 | |
| Contribution out of Revenue ... ... ... | 760 8 1 | |
| | | 46,362 18 5 |
| „ Economic Life Assurance Society :— | | |
| On Mortgage of Institution Building (1909) ... | 26,000 0 0 | |
| Since repaid ... ... ... ... ... | 6,425 16 7 | |
| | 19,574 3 5 | |
| On Mortgage of Tothill Street Buildings and Site (1910) ... ... ... ... ... ... | 11,500 0 0 | |
| | | 31,074 3 5 |
| „ Life Compositions Fund :— | | |
| Balance at 1st January, 1918 ... ... ... | 5,283 9 0 | |
| Life Compositions received in 1918 ... ... | 44 2 0 | |
| | 5,327 11 0 | |
| *Less* Life Compositions of Deceased Members transferred to General Fund ... ... ... | 125 8 0 | |
| | | 5,202 3 0 |
| „ Kelvin Lecture Fund :— | | |
| As per last Balance Sheet ... ... ... ... ... ... | | 648 13 0 |
| „ Paul Scholarship Fund (Donation received from Mr. R. W. Paul) ... ... ... ... ... ... ... | | 500 0 0 |
| „ Trust Funds Capital Accounts :— | | |
| Salomons Scholarship ... ... ... ... | 2,126 19 3 | |
| David Hughes Scholarship ... ... ... ... | 2,000 0 0 | |
| Wilde Benevolent Fund ... ... ... ... | 1,846 4 6 | |
| | | 5,973 3 9 |
| „ Trust Funds Income Accounts :— | | |
| Balances unexpended :— | | |
| Salomons Scholarship ... ... ... ... | 223 14 0 | |
| David Hughes Scholarship ... ... ... ... | 256 17 9 | |
| Wilde Benevolent Fund ... ... ... ... | 23 3 5 | |
| | | 503 15 8 |
| Invested Income (Wilde Benevolent Fund) ... ... ... | | 640 14 8 |
| „ Foreign Visit Fund ... ... ... ... ... ... ... | | 92 14 2 |
| „ Sundry Creditors ... ... ... ... ... ... ... | | 3,255 18 3 |
| „ Subscriptions received in advance ... ... ... ... | | 206 7 11 |
| Carried Forward ... ... ... ... ... | | 94,460 12 3 |

**Cr.** ASSETS.

| | £ s. d. | £ s. d. |
|---|---|---|
| By Institution Building and Lease :— | | |
| Cost ... ... ... ... ... ... ... ... | 73,028 6 10 | |
| *Less* Reserve for Depreciation, being Sinking Fund Premiums paid ... ... ... ... | 2,681 16 2 | |
| | | 70,346 10 8 |
| „ Sinking Fund (Premiums paid for Redemption of Cost of Building and Lease) ... ... ... ... ... ... ... | | 2,681 16 2 |
| „ Tothill Street Buildings and Site (at cost) ... ... ... | | 19,260 17 1 |
| „ Life Compositions Investments (at cost)* :— | | |
| £2,600 Natal Zululand Railways 3% Debentures | 2,270 12 0 | |
| £1,500 Lancashire and Yorkshire Railway 4% Preference Stock ... ... ... ... ... | 1,513 10 4 | |
| £2,000 Assam Bengal Railways 3% Stock ... | 1,548 0 6 | |
| | | 5,332 2 10 |
| „ Kelvin Lecture Fund Investment (at cost)* :— | | |
| £694 16s. 9d. 5% War Stock ... ... ... ... ... | | 648 13 0 |
| „ Paul Scholarship Fund Investment (at cost)* :— | | |
| £500 5% National War Bonds ... ... ... ... ... | | 500 0 0 |
| „ Trust Funds Investments (at cost)* :— | | |
| Salomons Scholarship :— | | |
| £1,500 New South Wales 3½% Stock ... ... | 1,556 5 9 | |
| £500 Cape of Good Hope 3½% Stock ... ... | 570 13 6 | |
| | | 2,126 19 3 |
| David Hughes Scholarship :— | | |
| £2,045 Staines Reservoirs 3% Guaranteed Debenture Stock ... ... ... ... ... | 1,998 15 0 | |
| Cash at Post Office Savings Bank ... ... ... | 1 5 0 | |
| | | 2,000 0 0 |
| Wilde Benevolent Fund (Capital Account) :— | | |
| £875 Great Eastern Railway Metropolitan 5% Guaranteed Stock ... ... ... ... ... | 1,493 16 3 | |
| £215 North Eastern Railway 4% Guaranteed Stock ... ... ... ... ... ... | 250 19 9 | |
| £100 London County 3½% Stock ... ... ... | 101 8 6 | |
| | | 1,846 4 6 |
| Wilde Benevolent Fund (Income Account) :— | | |
| £250 New South Wales 4% Stock ... ... | 251 6 0 | |
| £100 3½% War Stock ... ... ... ... | 94 8 8 | |
| £100 5% War Stock ... ... ... ... ... | 95 0 0 | |
| £200 5% National War Bonds ... ... ... | 200 0 0 | |
| | | 640 14 8 |
| „ Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust) :— | | |
| As per last Balance Sheet ... ... ... ... | 1,184 18 1 | |
| Additions in 1918 ... ... ... ... ... | 50 2 6 | |
| | 1,235 0 7 | |
| *Less* Depreciation (10%) ... ... ... ... | 123 10 1 | |
| | | 1,111 10 6 |
| Carried Forward ... ... ... ... | | 100,495 8 8 |

## BALANCE SHEET—*continued.*

**Dr.** LIABILITIES—*continued.*

| | £ s. d. | £ s. d. |
|---|---|---|
| Brought Forward ... ... ... ... ... ... | | 94,460 12 3 |
| To Repairs Suspense Account :— | | |
| Balance (as per last Balance Sheet) ... ... | 396 13 10 | |
| Amount set aside in 1918 ... ... ... ... | 400 0 0 | |
| | 796 13 10 | |
| *Less* Expenditure on Repairs in 1918... ... | 25 6 2 | |
| | | 771 7 8 |
| „ Reserve Fund (Contingencies and Mortgage Redemption) ... | | 8,000 0 0 |
| „ General Fund :— | | |
| Balance at 1st January, 1918 ... ... ... | 30,232 7 1 | |
| Life Compositions of Deceased Members ... | 125 8 0 | |
| Expenditure in 1918 on— | | |
| Books and Binding for Library ... ... | 50 2 6 | |
| Unexpended Revenue for 1918 ... ... ... | 1,270 11 5 | |
| | 31,678 9 0 | |
| *Less* Depreciation (*per contra*) :— | | |
| Library ... ... ... ... £123 10 1 | | |
| Furniture, Fittings, and Apparatus 112 5 3 | | |
| | 235 15 4 | |
| | | 31,442 13 8 |

J. E. KINGSBURY,
*Honorary Treasurer.*
P. F. ROWELL,
*Secretary.*

£134,074 13 7

**Cr.** ASSETS—*continued.*

| | £ s. d. | £ s. d. |
|---|---|---|
| Brought Forward ... ... ... ... ... ... | | 100,495 8 8 |
| By Thompson Memorial Library (Contribution towards purchase) ... ... ... ... ... ... ... ... | | 1,000 0 0 |
| „ Furniture, Fittings, and Apparatus :— | | |
| As per last Balance Sheet ... ... ... ... | 2,245 5 1 | |
| *Less* Depreciation (5 %) ... ... ... ... | 112 5 3 | |
| | | 2,132 19 10 |
| „ Sundry Debtors ... ... ... ... ... ... ... ... | | 2,003 14 5 |
| „ Insurance Premiums and Sundry Payments in Advance ... | | 374 10 10 |
| „ Stock of Paper for Publications ... ... ... ... ... | | 420 6 7 |
| „ General and Reserve Funds Investments (at cost)* :— | | |
| £750 Western Australia 4 % Stock ... ... ... | 730 8 3 | |
| £750 Union of South Africa 4 % Stock ... ... | 742 12 0 | |
| £750 Madras and Southern Mahratta Railway 4 % Debenture Stock ... ... ... ... ... | 738 15 6 | |
| £35 East Indian Railway "B" Annuity ... ... | 791 5 4 | |
| £1,500 South Australian 4% Stock ... ... ... | 1,494 10 6 | |
| £5,250 5 % War Stock ... ... ... ... ... | 4,987 10 0 | |
| £10,500 5 % National War Bonds ... ... ... | 10,500 0 0 | |
| | | 19,985 1 7 |
| „ Cash in Hands of Territorial Centres on 30 Sept., 1918 ... | | 109 5 2 |
| „ Cash :— | | |
| At Bankers' ... ... ... ... ... ... | 2,147 0 0 | |
| At Post Office Savings Bank (David Hughes Scholarship Trust Fund Uninvested Income) ... ... | 0 1 9 | |
| In hands of Secretary ... ... ... ... ... | 6 4 9 | |
| | | 2,153 6 6 |
| | | £134,074 13 7 |

* The above values are subject to depreciation.

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1918, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

ALLEN, ATTFIELD & CO., *Auditors,*
Chartered Accountants,
147, Leadenhall Street, E.C. 3.

*7th May*, 1919.

## SALOMONS SCHOLARSHIP TRUST FUND (Income).

| Dr. | £ s. d. | Cr. | £ s. d. |
|---|---|---|---|
| To Balance carried to Balance Sheet ... ... ... ... ... | 223 14 6 | By Balance (as per last Account) ... ... ... ... ... ... | 148 0 9 |
| | | „ Dividends received in 1918 ... ... ... ... ... ... | 75 13 9 |
| | £223 14 6 | | £223 14 6 |

## DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

| Dr. | £ s. d. | Cr. | £ s. d. |
|---|---|---|---|
| To Balance carried to Balance Sheet ... ... ... ... ... | 256 17 9 | By Balance (as per last Account) ... ... ... ... ... ... | 196 13 3 |
| | | „ Dividends received in 1918 ... ... ... ... ... ... | 60 4 0 |
| | | „ Interest do. do. ... ... ... ... ... ... | 0 0 6 |
| | £256 17 9 | | £256 17 9 |

## WILDE BENEVOLENT TRUST FUND (Income).

| Dr. | £ s. d. | Cr. | £ s. d. |
|---|---|---|---|
| To Amount invested during 1918 :— | | By Balance (as per last Account) ... ... ... ... ... ... | 43 0 8 |
| £100 5% National War Bonds ... ... ... ... ... | 100 0 0 | „ Dividends received in 1918 ... ... ... ... ... ... | 77 15 11 |
| „ Balance carried to Balance Sheet ... ... ... ... ... | 23 3 5 | „ Interest do. do. ... ... ... ... ... ... | 2 6 10 |
| | £123 3 5 | | £123 3 5 |

## RESEARCH ACCOUNT (1918)

| Dr. | £ s. d. | Cr. | £ s. d. |
|---|---|---|---|
| To Expenditure on Research on Buried Cables ... ... ... ... | 117 14 8 | By Unexpended Balance from 1917 ... ... ... ... ... ... | 322 10 3 |
| „ Expenditure on Research on Insulating Oils ... ... ... ... | 479 1 7 | „ Grants from Research Department ... ... ... ... ... | 400 0 0 |
| „ Balance carried forward ... ... ... ... ... ... ... | 281 10 7 | „ Grant from Institution ... ... ... ... ... ... ... | 145 10 0 |
| | | „ Interest ... ... ... ... ... ... ... ... ... | 10 6 7 |
| | £878 6 10 | | £878 6 10 |

# THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

## INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1918.

| Dr. Expenditure. | £ s. d. | Income. | £ s. d. | Cr. |
|---|---|---|---|---|
| To Grants | 229 15 0 | By Dividends on Investments | 233 11 0 | |
| „ Printing, Stationery, and Postage | 11 14 2 | „ Interest | 2 8 5 | |
| „ Unexpended Balance carried to Balance Sheet | 253 14 1 | „ Annual Subscriptions | 120 5 6 | |
| | | „ Donations of £5 and over | 115 8 4 | |
| | | „ Donations under £5 | 23 10 0 | |
| | £495 3 3 | | £495 3 3 | |

## BALANCE SHEET, 31ST DECEMBER, 1918.

| Dr. Liabilities. | £ s. d. | £ s. d. | Assets. | £ s. d. | £ s. d. | Cr. |
|---|---|---|---|---|---|---|
| To Capital Account : | | | By Investments (Capital), at cost :— | | | |
| As per last Balance Sheet | £4,642 3 0 | | £961 7s. 7d. Cape of Good Hope 3 % Stock | | 950 0 0 | |
| Amount transferred from Income Account in 1918 | 1,067 6 6 | | £593 1s. 7d. New South Wales 3 % Stock | | 600 0 0 | |
| | | 5,709 9 6 | £420 Great Eastern Railway 4 % Preference Stock | | 503 18 3 | |
| „ Income and Expenditure Account :— | | | £600 North Staffordshire Railway 3 % Debenture Stock | | 551 0 9 | |
| As per last Balance Sheet | £2,062 12 2 | | £750 East Indian Railway 3½ % Debenture Stock | | 737 18 0 | |
| Unexpended Balance in 1918 | 253 14 1 | | £300 London and North-Western Railway 4 % Guaranteed Stock | | 333 11 6 | |
| | 2,316 6 3 | | £500 New Zealand 3½ % Stock | | 486 18 6 | |
| *Less* Amount transferred to Capital Account in 1918 | 1,067 6 6 | | £500 Canada 3½ % Stock | | 478 16 0 | |
| | | 1,248 19 9 | £1,126 6s. 3d. 5 % War Stock | | 1,067 6 6 | |
| „ Sundry Creditors | | 27 3 11 | | | 5,709 9 0 | |
| | | | „ Investments (Income), at cost :— | | | |
| | | | £350 New South Wales 4 % Stock | £336 18 6 | | |
| | | | £200 3½ % War Stock | 188 17 3 | | |
| | | | £300 5 % National War Bonds | 300 0 0 | | |
| | | | | | 825 15 9 | |
| | | | „ Sundry Debtors | | 280 0 0 | |
| | | | „ Cash :— | | | |
| | | | At Bankers' | £147 8 8 | | |
| | | | In hand | 22 19 3 | | |
| | | | | | 170 7 11 | |
| | £6,985 13 2 | | | | £6,985 13 2 | |

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Bankers. The Investments, which are stated at cost, are subject to depreciation.

*7th May*, 1919.

JAS. ATTFIELD, F.C.A., *Honorary Auditor.*

# THE INSTITUTION.

## ADDRESS TO THE TERRITORIAL CENTRES

By C. H. Wordingham, C.B.E., President.

(*Address delivered at* Birmingham, 5 *November*, 1918; *at* Cardiff, 11 *November*, 1918; *at* Newcastle, 25 *November*, 1918; *at* Leeds, 26 *November*, 1918; *at* Manchester, 10 *December*, 1918; *and at* Glasgow, 16 *December*, 1918.)

Gentlemen,

### Introductory.

I am exceedingly pleased again to have the opportunity of addressing you and I make no apology for once more taking as my subject the Institution. Presidents and Chairmen come and go and their prominence rapidly wanes but the Institution endures and waxes and each of us who is called to office must do his best to lay well and truly a few bricks which shall be part of the permanent structure that we hope to see tower up to heights not hitherto contemplated.

I propose briefly to review some of the principal incidents of last Session ; next to indicate some of the matters which I think press most for immediate attention and then to pass on to the consideration of the future of the Institution.

### Territorial Centres.

One of the most conspicuous things we did last Session was to improve the status and extend the responsibilities and possibilities of what were then called Local Sections. We have renamed them " Territorial Centres " and we now call them by the names of different parts of the country instead of by the name of an individual town or city in order to emphasise that they cover a whole area and are not simply local to one town. The expression " Territorial Centre " is not a particularly happy one but no better has been suggested at present ; it has the merit at all events of getting away from the idea that there are any " sections " in the Institution. Each member is just as much a member of the Institution if he lives in the remotest part of the country as if he lives in London, and we are trying to secure to him as many privileges.

Very much more responsibility is now given to the Committees of the Centres, and they are taken fully into the confidence of the Council. In the past the Chairman alone was conversant with what went on in the Council ; he was bound down by promise of secrecy not to tell his Committee what passed at the Council meetings and in consequence was often placed in a most invidious position. That condition has now been done away with and the Chairman is at liberty to communicate the whole of the Minutes of the Council to all the members of his Committee. This will enable them to follow and keep in close touch with all that is going on in the Council and the Chairmen can adequately give expression to the views of their respective Centres. That I think is a very great gain.

In the case of some Centres local committees are being formed under the auspices of the Territorial Centres Committee to aid in the research work of the Institution and permission has been given to the Centres to inaugurate and carry on co-operation with other engineering bodies in their district subject to the approval of the Council to act on behalf of the Institution for this purpose. This is I think a very important feature and one that should lead to much usefulness.

With the increased privileges of the Territorial Centres there comes a corresponding increase in responsibility and it is for each Centre to make it its business to see that the powers of co-operation with other bodies which have been conferred on it by the Council are exercised in such a way that the Institution is not left out of any electrical question in the district of which the Centre is the focus. Also it is for the members of each Centre to see that no man who is properly qualified for membership is left outside the Institution.

### Electrical Proving House.

Another matter to which a great deal of attention was devoted last Session and which made considerable progress was the question of the Electrical Proving House. That matter has now advanced to the stage of a definite scheme having been formulated. All the constituent bodies called together to consider the subject under the auspices of the Institution are now in possession of that scheme. I am a strong believer in the good that will be effected by such an institution.

There are one or two questions outstanding which will have to be settled before we can make any real progress. One of these is whether the Proving House should test only goods of British (that is to say of Imperial) origin or whether it should also be prepared to test imported goods and to certify whether they do or do not comply with British standard specifications. There is room for difference of opinion on that point. For my own part, at all events in the earlier stages, I felt most strongly we should only test goods of British origin but it has been put forward by manufacturers that if we do that there is danger that other countries may retaliate against our goods when they are exported to those countries. Well, I am not aware that foreign countries have ever shown much favour to British goods in the sense of making facilities for them to enter and I do not know that this action of the Proving House would make matters very much worse. But it is an important point and it will have to be thoroughly discussed. It has been suggested that we might have

reciprocity in the matter, and that in the case of those foreign countries which set up Proving Houses of their own, if they are willing to accept the certificates of our Proving House, we should be prepared to test their goods or to accept their certificates in regard to the compliance of goods with the specifications.

There has been one other point that has been raised namely that in certain quarters we are told support will not be forthcoming unless some arrangements can be made to enforce the use of articles only which have passed the Proving House. That is a very difficult matter to arrange as will be obvious and my own personal view is this—let us get the Proving House started and all these other matters will very rapidly settle themselves. I am convinced that once it is on its feet manufacturers and all concerned will find it is of such enormous benefit that they will not hesitate to make use of it. I do not believe in considering every possible difficulty that may arise beforehand. It is far better to get the thing started and deal with the difficulties as and when they arise.

I think you are aware that it has been proposed that the Proving House should be worked in conjunction with the National Physical Laboratory. That is now under the Government, though it is administered by an Executive Committee appointed by the Royal Society, and there may be some difficulty in commercial testing being done by such a body, but I am hopeful that this difficulty also will be overcome.

### Electrical Development Association.

Another important step taken last Session was the formation of the Electrical Development Association. This was formed as the immediate outcome of Mr. Gillott's paper on Heating and Cooking which was read last Session. At the end of that paper he suggested the formation of an Association of the kind for heating and cooking. We called together the parties concerned and it was decided to launch such an Association, but to extend its scope so as to cover the commercial development of all kinds of electrical activities. Obviously the Institution could not undertake that work because it consists largely of publicity and is wholly commercial, but the Institution has fostered the Association and will be represented on its Governing Body, so that there will be a close union between the two. I am confident that this Association, if properly worked, will have a most important bearing on the Industry in the future.

### Patent Law.

A very important Committee was set up last Session in connection with the question of Patent Law. When the Patent Bill was introduced by the Board of Trade we wrote asking that the views of our members might be heard before the Bill became law. As a matter of fact the Bill was dropped for other reasons; the Board of Trade, however, replied to our communication to the effect that the Bill was not being proceeded with, but that they would be very happy to hear our views. Accordingly the Committee, which was under the chairmanship of one of our Past Presidents, Mr. Mordey, set to work and produced an admirable Report which has now been published in the Press. Meanwhile the Institution of Mechanical Engineers had called a Conference of practically all the Associations which were in any way interested in Patents, and, to make a long story short, that Conference adopted our Report en bloc as their own, which I think was a very gratifying result. A very influential Deputation was appointed to wait on the Board of Trade, and some six or seven speakers, each taking a different aspect of the case, put forward the views of the Conference before the Board of Trade representative. The Deputation was complimented on the way in which the matter was dealt with and there is reason to hope that full weight will be given to the views expressed in a new Bill which is about to be drafted.

### Appointments Board.

Last Session the Council determined to set up what is known as the Appointments Board. That was initiated by a desire on our part to do something to further the employment of those returning to civil life from service in His Majesty's Forces. But it was felt that there was no reason so to limit the usefulness of this Board and accordingly it was decided to let it deal with the cases of all members of the Institution who are seeking fresh employment. This Session the Board has actually been appointed and it is now at work. It will only deal with those who are out of employment and will endeavour to bring them in contact with employers who are seeking assistants. It was felt that it would be undesirable to deal with the cases of those who were actually in employment but wished to obtain better employment, because it would interfere between employers and their staffs and might lead to very undesirable consequences. In order to comply with legal requirements it is necessary that the Board should be an entirely separate organisation from the Institution but it will be run exclusively by members of the Institution for members of all grades. I look forward to this being of great value especially to the younger members.

### Radiography.

It will be remembered that last Session we had a joint meeting with a branch of the Royal Society of Medicine known as the Association of Radiography and Electrotherapy. We had two excellent papers read by Doctors and a very good discussion ensued. The direct outcome of that was that we have formed a Joint Committee with this Society to deal with the question of providing efficient lay helpers in connection with X-ray and Electro-therapeutical work. The doctors felt the need of some criterion of proper training of those men whom they employed to help them to administer the treatment and to look after the repair of the apparatus they used. It was felt that it would not be desirable to grant a diploma to these men because you could not withdraw such a diploma if they acted improperly. Once given, it could not be taken away. There is the danger that these men with no medical knowledge after helping doctors to give the treatment

might start giving treatment themselves. That would be dangerous to the public and objectionable from the point of view of the doctors, and in order to keep some hold upon them it has been decided to deal with the matter in the following way:—These men are not ordinarily of the calibre that would entitle them to be elected to any grade of the Institution but they must have a certain amount of training. An Association especially for them therefore is to be formed and managed by a Joint Board drawn one third from the Royal Society of Medicine and one third from the Institution the remaining third consisting of radiographers. The Board will arrange for courses of training and for the holding of Examinations, and those who are successful in passing the examinations will be eligible for membership. So long as they conduct themselves in accordance with the Rules they will continue members. If any behave improperly they will cease to be members of the Association. In that way I think we shall secure thoroughly efficient lay helpers of the kind and retain the control over them which is necessary in the interests of the public and the Medical Profession.

### Joint Meetings.

Joint meetings of this kind are I think of the greatest possible value to the Institution. As I said just now we have arranged to have another joint meeting with this Medical Society. Last year papers were read by the Doctors ; this year one of our own members is reading papers. As on the last occasion there will be an exhibition of apparatus. We have also arranged a joint meeting with the Iron and Steel Institute in May, at which papers on Electric Furnaces will be discussed. We felt that a subject of that kind could only be adequately discussed if we had the users of the furnaces present as well as the makers. We have a number of valuable papers already and I think we can look forward to a very excellent discussion. There are other joint meetings contemplated but I need not go into the details of those. I hope co-operation with other Societies in this manner will be a permanent feature of our work.

### Technical Co-operation Committee.

Recently a Committee, which I think will be very important, has been set up by the Institution, known as the Technical Co-operation Committee. That Committee is intended to deal with all questions affecting the Institution which arise from foreign countries. To take a case in point : the Institution is at present drawing up rules in connection with the electrical equipment of ships. Now ships peculiarly require uniformity of rules because they are installations which move about all over the world, and it is an immense gain to the shipowner if he can find in every port to which his ship goes spare parts suitable for his installation. Therefore it is very desirable that our rules should agree with the rules say in America, and the Americans are at present considering that question ; so also are the Italians. Then again it is very desirable to be able to interchange experiences. Enquiries are sometimes sent over from foreign countries as to English practice in certain respects. This Committee will be charged with the duty of answering such questions, and when British engineers want to know the practice in foreign countries the Committee will endeavour to obtain information. We hope foreign countries will set up Committees of their own on similar lines which will be able to answer our enquiries. We are already suggesting such a Committee to America. One hopes that as a result of this interchange of experiences this Committee will do a good deal to bring together the Electrical Engineers of the allied nations and to foster a feeling of greater harmony.

### The Institution and Overseas Dominions.

I have given you a brief sketch of the salient features of last Session's work and will now turn to a few questions which I think call very urgently for action during the present Session. Last Session, as I have said, we dealt as effectually as we could with the question of Local Sections. The Dominions beyond the Seas and the scope of our Institution in them call at least as urgently for immediate action. At present we are not doing very much as an Institution abroad. In Canada the American Institute has to a very great extent already captured the field and anything that we do must be more or less in competition with them. It would be lamentable were a similar position to develop in Australia and New Zealand, for example, or in India, and it is most important that we should attack this question and see on what lines it should be approached. I think we ought to take a very broad view of the matter and recognise that we cannot expect these great Dominions to be considered as Territorial Centres, on the same footing as a comparatively small section of the British Isles. We must recognise their national aspirations, and, subject to modification later on, my present view is that we should endeavour to work on some such lines as these : Each of these Dominions, say Canada or Australia or India, should have its own Engineering Institution, and our members should in some way be affiliated, as a Section of this Institution to what I may call the National Institution. In those countries in which the total number of Engineers is small there might be one National Institution for all kinds of Engineers, in others there might be enough Electrical Engineers to justify a National Electrical Institution. In either case our members in the Overseas Dominions while remaining members of our own Institution and meeting together should in some way be affiliated to that Overseas National Institution, so that Canadians or Australians or whoever they were would feel that they were not joining a purely English Institution, but that they were joining a Canadian or Australian Institution closely interlinked with our own British Institution of Electrical Engineers. I think it is the duty of our Institution to foster in that way the interests of Electrical Engineers all over the British Empire, and I think that the matter should be taken in hand forthwith.

### Protective Associations.

Now I come to what is perhaps the most burning question which requires to be dealt with this Session.

I have not yet mentioned what certainly entailed on me personally by far the greatest amount of work last Session, namely, the forming of a protective Association for Power Station Engineers. I should like to refer to that at some length. I will first recite briefly the history of what took place. Towards the latter end of last year the Council were informed that very strenuous efforts were being made by the Electrical Trades Union to bring within its membership not only workmen, but engineers of all ranks up to and including Chief Engineers of Central Stations. Obviously that was an intolerable position, and it was incumbent upon the Institution to do something for its members. The Government has put upon us as a body of men the obligation to organise ourselves. The Government practically insist upon all industries being organised. They will not deal with individuals; they will only deal with organisations. The Whitley Report most unfortunately recognises only two classes: workmen and employers. The brains of manufacturing Works and of all Technical Industries are left out altogether. (When I say the brains I mean the technical staffs; if you withdraw the technical staff from a manufacturing concern, you have practically no industry left; there is no one to guide the workmen, and no one to ensure the proper employment of the capital of the employer.) It is a gross injustice and a most extraordinary oversight. Seeing that something must be done to organise the technical staffs it is necessary to consider how that organisation can best be effected. I think you will all agree that you cannot have the technical staffs in the workmen's Union. The Council were faced with this position: They were informed that there were some half dozen Associations intended to be protective Associations, but all very much on a par with one another, and it appeared hopeless, from the information we had, for any one of these Associations to swallow up the others and produce one representative Association. Now it is one of the cardinal principles of a protective Association, I think, that it should be comprehensive and that there should be no competitive Associations—only one Association for a given industry. Therefore having regard to the facts as they were presented to the Council, the Council said to themselves: the only way we can reconcile these half dozen Associations is by the Institution starting an altogether new one under its auspices which the members of these other Associations can join without any loss of dignity and without allowing one Association to think it had got the pull over the others. Accordingly at most of the Local Sections there were arranged so called Mass Meetings at which the proposals of the Council were explained and were discussed.

Now I want to make quite clear that the only object of the Council was to provide a representative protective Association which every one of its members could join. They had no other object in view. When these Mass Meetings came to be held, however, very violent opposition was experienced from one of these half dozen bodies, namely, the Electrical Power Engineers Association. It became quite clear as a result of these meetings (and I may say as a result of my own personal enquiries and of my meeting with the members of the E.P.E.A.) that whatever may have been the case when the information was prepared on which the Council acted this Association had far outdistanced all the others and was in fact vastly more important than the remaining ones in respect of numbers and of the support which it had received from the Power Station men concerned. That was demonstrated quite clearly. Further than that, they had a most important asset in that they were constituted before the outbreak of war as a Trades Union. Now the Trades Union idea was a very bitter pill to most of us to swallow. I do not pretend for a moment that any one of the Council, nor in fact many members of the Association itself, wished to promote or to join a Trades Union, but that is practically put upon them by the Government. Unless you are one you are no better than a Mutual Admiration Society. In order to act effectually you must be a Trades Union, whether you like it or not. Some of us have gulped at this pill and some of us have more or less choked over it; but it has had to be swallowed.

I want now to make clear that there has been no climbing down on the part of the Institution Council in respect of this matter. As soon as the facts were found to be different from the facts which were put before the Council, on which facts they had acted, the Council said: here is an Association which is capable of swallowing these other Associations and there is no need for us to form another Association. The last thing in the world that was desired was to compete with a suitable existing Association. The only object of the Institution in trying to start the new one was to eliminate the competition which already existed between the half dozen Associations then in being. If it were possible to utilise one of these and take that as the Institution Association, well and good; we wanted nothing better; and the upshot of it was that the Institution recognised the E.P.E.A. as *the* protective Association for Engineers engaged in the Power Station industry. And there the matter stands at the present moment.

Now as the Institution has dealt with Power Station members it has an equal duty to those other members who are engaged in the manufacturing industry, and something ought to be done for them. As is well known to all of you, there is already in existence a Society known as the Society of Technical Engineers (though I confess I do not quite know what sort of an Engineer he is who is not a technical engineer). That has been in being for some considerable time, but, for reasons which I believe are very good and sufficient, there has been a great deal of secrecy about this Society and very little if anything has been published. As a matter of fact I have been in touch with members of this Society practically since its inauguration. I have therefore known (in my personal capacity) the general trend of events. From time to time I have endeavoured to make clear that the Institution would welcome any suitable Society which would care for the other members of the Institution who were not provided for by the E.P.E.A. For some reason there has been in the past a strong feeling of hostility towards all the old Institutions—Electrical, Civil and Mechanical

—on the part of this new Society. The Society is not purely electrical, it embraces all branches of engineering, and for that reason it has been quite impossible for our own Institution to approach the Society because we should have laid ourselves open to a very well-merited snub. We might have been asked what we were interfering with them for when they were not electrical. Therefore nothing has been done officially, but unofficially I have endeavoured to get in touch with the movement; I am very glad to think that a much better feeling is growing up towards the Institution and I look forward to co-operation with the Society before very long.

I am a very strong believer in the co-operation of all branches of engineering in a matter of this kind but there is room for a good deal of difference of opinion as to the way in which co-operation should take place. Until recently I held the view very strongly that the best way of co-operating was to have a separate Association for each main branch of engineering and for those Associations to co-operate as Associations for any common end that was desirable. The advantage of that is that you are certain of being able to act with unanimity if you are only concerned with one branch whereas if you have a hetereogenous Association formed on the lines of the S.T.E. you may be able to secure agreement in ninety nine cases but there may be one case in a hundred where the interests of the different bodies of members are antagonistic and in that case it is impossible for the Society to act as a whole because it would never do for it to espouse the interests of one section of the members if those interests were antagonistic to the interests of another section. With this scheme of separate Associations you can act jointly in the ninety nine cases and in the hundredth each Association can act independently.

That sounds plausible and that was my view until quite recently, but as the result of conversations I have had with some of the leading men in this movement I am inclined to think there is a good deal to be said for the line they have taken. It has been pointed out to me that in many of the large works you have staffs belonging to quite different branches and by pursuing what I may call the separate scheme you would have the members of one staff members of different Associations which is very undesirable. It is important that all the members of the staff of one firm should be members of the same and only one Protective Association. It may well be that the advantages of that outweigh the disadvantages which I have pointed out. Personally I have a perfectly open mind in the matter. The only thing I do press most strongly is that the matter is urgent and that we should get a single Protective Association for the whole of our members in whatever branch of electrical work they practise.

It appears to me it might be possible to extend the Electrical Power Engineers Association so as to include all electrical engineers and to embody it in the Society of Technical Engineers. I do not carry the matter any further at the present moment. In fact we cannot do much unless and until we are in some way approached and I do not think that the S.T.E. will be able to approach us until they are able to approach the other Institutions—the Mechanicals and the Civils; personally I have tried to pave the way with the Mechanicals. Whether it will be possible to bring in also the Institution of Civil Engineers is another matter. On that I am not so hopeful because they are certainly in a different category. They do not include among their full members many manufacturers. They are more strictly a professional class than are our members as a whole.

Before leaving the subject I would like to urge one thing and that is this; the E.P.E.A. is very young and it has many young men within it. It may in the earlier stages act indiscreetly at times. It should not be condemned for that; rather should every effort be made to secure that the governance of that body is effected by men who will have plenty of common sense and moderation and will run it on proper lines; but whatever they do, try to meet them and do not try to set up competitive organisations which can only end in failure, for any competition must tend to destroy the usefulness of all those who are competing. After all what we have to fight is a common enemy.

With regard to the E.T.U. we do not even want to fight them. I should like to see some rapprochement between the Union and the E.P.E.A. Hitherto they have been at loggerheads because the E.T.U. has been endeavouring to bring within its ranks those who properly speaking ought never to be there. If only these two bodies could agree upon a line of demarcation then there is no reason why one should not be helpful to the other. So long as the E.T.U. endeavour to force engineers into their ranks so long must they be regarded in a hostile spirit by the engineers, who never can possibly in any numbers I should hope enter that Union; not because there is anything derogatory in their doing so but because there is an essential difference between manual work and technical and scientific work.

### Junior Members.

The next matter which I think ought to receive attention is the doing of something more by the Institution for its junior members. There is a tremendous gap between the Students' meetings and the general meetings of the Institution in London and at the Territorial Centres. I hold most strongly that all technical discussions should be held under the auspices of the Institution. The Protective Associations should confine their attention to the objects for which they were founded. I think it would be a very great mistake if they were to start reading papers on technical subjects as has been proposed, but, in saying that when I was consulted on the matter, I met with the retort that it is essential that these younger men should have the opportunity of reading papers and taking part in discussions, that they were not qualified to join in the main meetings either as authors of papers or in discussions, and if they did not have facilities they would never get the practice which was necessary to enable them to become competent authors and able to discuss papers of the general meetings. That,

gentlemen, I think is entirely true and it is certainly the duty of the Institution to provide those facilities. I felt so strongly about this that I brought the matter before the Council at its first meeting this Session and there is at present full consideration being given to the matter. I am hoping that something tangible will result very shortly. Just as we have a Committee of students which arranges Students' meetings at which papers are read by students and discussed by students, so I should like to see set up, and I am hopeful there will be set up, a Committee drawn from the junior members of the Institution above the grade of students but still not very far advanced in the profession who will arrange for the reading and discussion of papers by men of their own rank.* These discussions I should like to see conducted on informal lines much the same as is done at the meetings of the Junior Institution of Engineers. That Institution I believe is doing very good and useful work and we might very well follow their example in large measure in regard to our own younger members. I feel so very strongly that it ought not to be necessary for them to join another Institution in order to get the opportunity of obtaining practice in the reading and discussion of papers—not that I would in any way like to see the work of this excellent Institution of the Junior Engineers interfered with, but there is room for us to try to do something for our members without interfering with them in any way. I should hope it would be possible for us mutually to assist each other and possibly for these junior members to hold joint meetings from time to time with this Junior Institution of Engineers.

### Sectional Meetings.

Not only should we sectionalise by experience but also by subject. At the present time undoubtedly power station papers greatly preponderate but they are of very little interest to the telegraph and telephone section. On the other hand if we get a paper on telegraphs or telephones the power station men severely let it alone and do not go to the meetings. We cannot do everything at our ordinary meetings but I think we might set up separate Committees to deal with some of the more important sections. For example, wiring contractors are a very large and important body but we never by any chance have a paper dealing with wiring work. Again we might very well have a Committee for telegraphic work and let the telegraph men organise their own meetings and conduct their own discussions. There is a crying need for good work to be done in connection with wireless telegraphy.† We have practically no publication in this country in connection with wireless whereas in America there are splendid publications of the kind. That I think is a reproach to our Institution because after all we are charged with every branch of electrical work as it arises. The fact that we have not attended to these lesser known branches has led in the past to the formation of special societies. There ought to be no need for that; they ought to be dealt with by appropriate sections of the Institution—I do not for a moment suggest that we are in any way to damage those Societies which have already been set up, I would like, if possible, to get them to co-operate with us—but where new branches crop up it is very desirable that we should take action which will render it unnecessary to set up additional bodies with additional expensive subscriptions and wasted effort in organisation and so on. We ought to do the work ourselves.

### War Memorial.

I should like to commend to you a matter which when I wrote my address was in the future but which is now, I am happy to say in the past or rather in the present. That is the provision of a worthy, conspicuous, useful and lasting memorial to those of our members who have fallen in the war. There has been set up a Committee which has already held meetings and has carefully considered the lines which such a memorial should take. Nothing has yet been definitely settled but the general idea is to have a suitable tablet in the Institution headquarters commemorating the names and regiments of all those who have fallen and to devote the main portion of the money collected (which I hope will be a very substantial sum) to benefit the dependents of the fallen and those who have been permanently disabled in the war. I hope we shall not spend a penny on bricks and mortar and that we shall be able to act through existing organisations. I hope also that no capital sum will be carried forward in perpetuity but that the whole of the money collected will be spread over the lifetime of those who are in receipt of the help and no further; I do not like the idea which seems prevalent in some quarters of getting money which is badly wanted for some school or college or whatever it may be and calling it a memorial to those who have fallen. The memorial should be of active use to those who have suffered in their own persons or in the persons of their immediate dependents during the war. Those I hope will be the lines which our memorial will take.

I should like also to see the Institution out of its own funds publish a book containing a short biography of every one of its members who has fallen, together with a portrait. It would be an interesting and a very proper record, but I do not think that the cost should be charged to the War Memorial Fund; we can afford that as a record of the Institution's work.

### Activity and Leadership by the Institution.

In the brief review which I have given you I think two facts stand out. The first is that in several instances Papers read before the Institution have led to definite action being taken. That is a gratifying result. The second is that such action has been taken in concert with other bodies. The Institution, as it has been said, has been the umbrella under which a number of other bodies have met. On some six or eight occasions during last Session joint meetings of that kind took place. I will cite a few. The Patent Law Committee is an instance. We have at present a Committee sitting to consider the Board of Trade Reports, which

* This Committee is now in being and two informal meetings have already been held.

† The Wireless Sectional Committee is now in being and two meetings arranged by it have already been held.

are such momentous ones for the Industry, to endeavour to get the collective opinion of the Industry on those Reports. Then we did a good deal last Session in connection with Coal Rationing and Diesel Fuel. In the case of the Proving House and the Commercial Development Association again the Institution was the umbrella under which the parties interested met. I think this taking the lead has been a most useful and important development of the Institution's work.

### Charter.

You are aware that last year in my Inaugural Address I laid a good deal of emphasis on the obtaining by the Institution of a Charter, and a Charter Committee was set up last Session. The Committee met once and reported. Now it was quite clear when the meeting began that the members of the Committee thought that what they were expected to do was to draw up a scheme in the form of a Royal Charter having the same effect and the same objects as the scheme which is now embodied in our present Memorandum and Articles of Association, but I ventured to unfold to that Committee something of what was in my mind as to the future activities of the Institution and I am bound to say they were rather taken aback and the Report which they made to the Council was a very reasonable one indeed namely in effect that before they were asked to draw up a Charter it would be just as well if they knew what the Charter was to cover—in other words before they drew up the Specification it was necessary for them to know what they wanted. I feel most strongly that I have no right to go to the Council and ask them to draft a Charter on certain lines unless I am able to say that I have what I may call a mandate from the general body of members that the scheme I put before the Council is the scheme the members want. So, entirely on my own responsibility—I want to make quite clear that the Council is in no way responsible for the scheme I am putting forward—I have drawn up a scheme which will serve as a peg on which to hang a discussion and I am addressing each of the Territorial Centres in order to bring this scheme before as many individual members of the Institution as possible. That scheme does not profess to be perfect nor complete but it is sufficient I think to enable members to express a general opinion and to give a guide as to what they want the Institution to be. There are some of the elder members of the Institution who think that the members wish it to be merely a scientific and technical body for the discussion of papers on Engineering subjects. The impression which I have received, rightly or wrongly, is that the majority of the members want something very different. They all want that but they also want the Institution to develop the commercial side of the Industry. At this stage I suggest that members should ask me questions concerning the scheme but I do not ask them to discuss it. When I have been to all the Centres a full report of the Address will be published in the *Journal* and in the Press and after that publication has taken place each Centre I hope will see its way to call a meeting specially to discuss the scheme. It may be that all the Centres will condemn the scheme, it is possible that some or all of them may approve it, but I would ask that a resolution or resolutions be passed at each of these meetings saying something about the scheme—either commending it and showing that it is what the members want, or condemning it and showing it is what they do not want, in the latter case suggesting modifications or alternatives which will give a real lead to the Council as to what is wanted. Because, after all, the Council is only there to carry out the wishes of the general body of members and they do not want to force any scheme upon the members; they merely want to do what the members wish.

### Basis of Scheme.

Now with that preamble I will come to the scheme itself. It is founded on the action I have already referred to, namely the Institution serving as an umbrella under which other Associations can meet. They have already come together with most satisfactory results and have been able to take useful action in a number of cases. There can be no question of that. It seems to me that there is thus indicated the line we may profitably take, and that we should endeavour to get the Institution recognised as the body under whose wing all other Associations may come, and which will provide a common ground on which they can discuss matters affecting the Industry. As stated in my Inaugural Address, I have always taken the view that the Institution as it stands at present cannot possibly suffice for all the needs of the Industry. I think it is essential that every separate branch of the Industry should have its own Association to deal with its particular interests. We have the I.M.E.A. looking after the municipal interest, the Association of Power Companies looking after the Power Company interest, the B.E.A.M.A. looking after the Manufacturers, the Cable Makers Association looking after the manufacturers of cables, and so on, and I think that is altogether right, but I do think that it is equally essential that those Associations should also be gathered together under the Institution and that the umbrella should be a permanent tabernacle or permanent structure rather, so that instead of calling ad hoc Conferences all these Associations should regularly meet together under one Grand Council which would be the Council of the Institution. In this way matters affecting the Industry could be discussed in all their bearings, and when some question was raised outside there would be only one voice of the Electrical Industry to answer it. With such a question arising under the scheme I am about to outline the matter would be received by the Supreme Council and would be referred to the Association concerned. In most cases I believe it would be possible to secure agreement of all interests and that the supreme body could deal with the matter. There would quite possibly—most probably—remain certain matters on which agreement could not be secured, and then the individual Association would have to act by itself. But I believe it would be an enormous gain to get these various interests together round one table to discuss matters. Where interests at first appeared to be antagonistic, one would very soon find that there was a great deal to be said about each of them, and I believe

that by full discussion in that way, as a matter of course and periodically, it would be found that agreement was greatly facilitated and in most cases would be possible.

### Constitution of Grand Council.

I would invite your attention to Diagram No. 1. You will see that I propose the Institution should become the Royal Institution of British Electrical Engineers, or (if you will) the Royal Institute of Electrical Engineers, the "British" being assumed, and that it should be governed by a Grand Council. That Grand Council would have sent to it representatives of all important Associations and there would be under it a series of Councils as indicated on the diagram as follows :—

A Professional Council. I will come in a moment to what its sphere of action would be.

A Manufacturers' Council. The backbone of this would naturally be the B.E.A.M.A. and the Cable Makers' Association.

A Company Power Supply Council. The foundation of this would be the Incorporated Association of Electric Power Companies, the Power Supply Companies of Great Britain and the Conference of Chief Officials of the London Supply Companies.

A Municipal Power Supply Council. This would naturally be furnished by the I.M.E.A.

A Railways and Tramways Council. This would be drawn from the Tramways and Light Railways Association and the Municipal Tramways Association with representatives from the Railways.

A Mining Engineers' Council drawn from the Institution of Mining Electrical Engineers.

A Telegraph Council which would be drawn from the present Institution of Post Office Engineers and from the Submarine and Wireless Engineers.

A Plant Installers' Council. The Electrical Contractors' Association would naturally furnish the members of this.

A Research Council dealing with all matters of Research which would be practically the present Electrical Research Committee.

A Commercial Development Council which would be the new body I have mentioned as having been recently started under the auspices of the Institution.

A Protective Association Council which would be drawn from the E.P.E.A. and any other protective Association recognised by the Institution, as, for example, the S.T.E.

All these Councils would send representatives to the Grand Council in proportion to their importance. I will not enter into details as to how their importance is to be gauged or the precise number of their representatives fixed ; that is a matter of detail of great importance for careful discussion but I wish to make it quite clear that every one of the different Councils would be autonomous as now and that they would continue to act as at present independently in regard to the interests of their own members but they would each send representatives to the Grand Council before which all important matters affecting the Industry would naturally come. We have in fact during the past Session on some half dozen occasions, as I have already indicated, acted really as the Grand Council by means of ad hoc conferences. We have invited all these different bodies to be represented at a Conference called to consider and deal with a particular object and in every case something useful has resulted. When the representatives have met round a table they have found much common ground and have been able to take joint action. Any matters which came up from outside and affected the Industry would come before the Grand Council ; the Grand Council would refer the matter to the subordinate constituent Council for consideration and report and I am confident that in ninety nine cases out of a hundred it would be possible to get the Grand Council to adopt the report of the Constituent Council and reply to the outside authority in the name of the whole Industry. There would thus be one recognised authority to which all matters which affected the electrical industry would be referred by the Government or by any individuals or concerns and they would get an authoritative answer to whatever question they put to the Grand Council.

One effect of the scheme which I have outlined would be to prevent overlapping. At the present time practically every new electrical association that is formed for any purpose takes powers to deal with a number of matters which are already well looked after by existing institutions. My view most strongly is that, for example, a Protective Association should confine itself to protecting the commercial and material interests of its members and should not dabble in research or education or matters of that kind. Research should be left to the Research Council, and similarly in regard to other matters.

### Functions of Professional Council.

I will now return to the Professional Council and describe its functions in some detail. This Council would deal with the following matters :—

1. It would provide papers and organise discussions on scientific, technical and professional subjects generally.
2. It would have a well qualified staff with adequate Press experience to run all publications of the Institution.
3. It would have the care of the Library, the Lending Library and all periodical Journals.
4. It would publish bibliographies on all subjects of interest as well as digests, abstracts and memoirs so that it would be possible for the members to obtain a comprehensive and up to date account of all that is known up to the present of any particular branch which they wished to study or develop.
5. It would confer the right to practise in the different branches of Electrical Engineering.
6. It would deal with educational questions affecting electrical engineers and would hold examinations.

While the other Councils represent Associations formed for convenience to look after the material interests of particular sections of the electrical com-

ROYAL INSTITUTE OF BRITISH ELECTRICAL ENGINEERS
(I.E.E.)

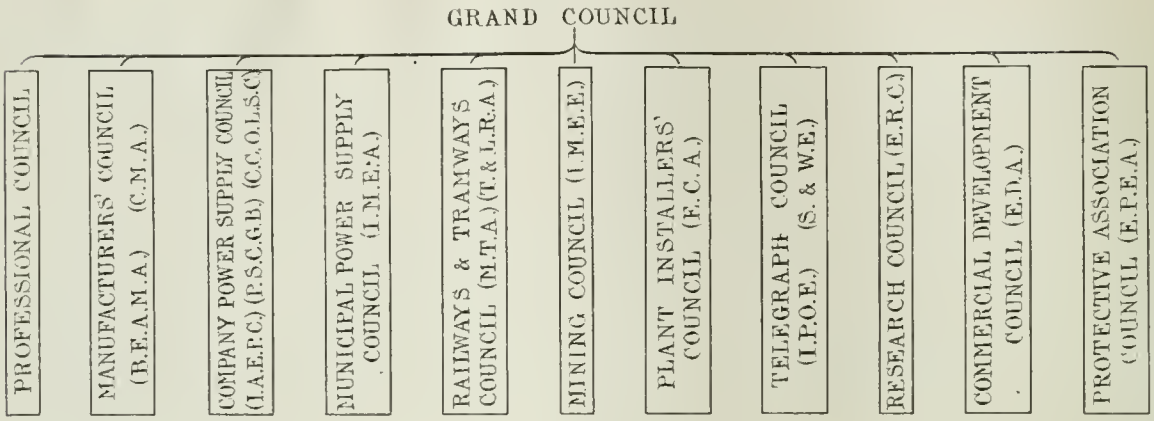
GRAND COUNCIL
PROFESSIONAL COUNCIL
MANUFACTURERS' COUNCIL (B.E.A.M.A.) (C.M.A.)
COMPANY POWER SUPPLY COUNCIL (I.A.E.P.C.) (P.S.C.G.B.) (C.C.O.L.S.C.)
MUNICIPAL POWER SUPPLY COUNCIL (I.M.E.A.)
RAILWAYS & TRAMWAYS COUNCIL (M.T.A.) (T. & L.R.A.)
MINING COUNCIL (I.M.E.)
PLANT INSTALLERS' COUNCIL (F.C.A.)
TELEGRAPH COUNCIL (I.P.O.E.) (S. & W.E.)
RESEARCH COUNCIL (E.R.C.)
COMMERCIAL DEVELOPMENT COUNCIL (E.D.A.)
PROTECTIVE ASSOCIATION COUNCIL (E.P.E.A.)

Diagram No. 1.

REPRESENTATION ON PROFESSIONAL COUNCIL

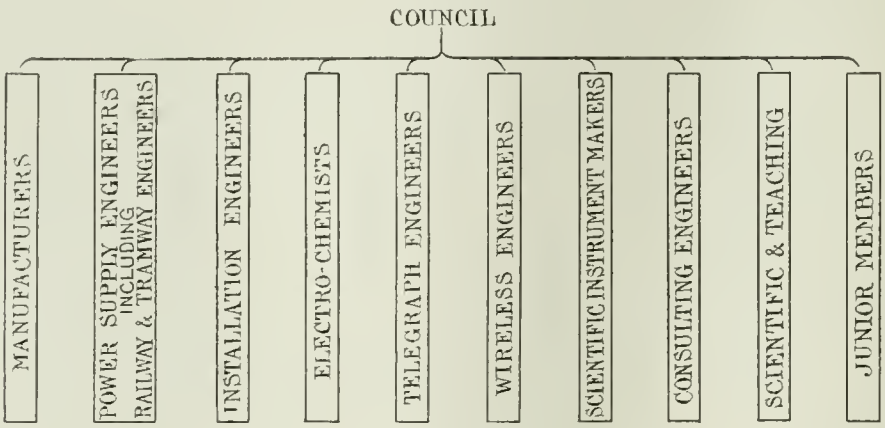


Diagram No. 2.

ORGANISATION OF PROFESSIONAL COUNCIL

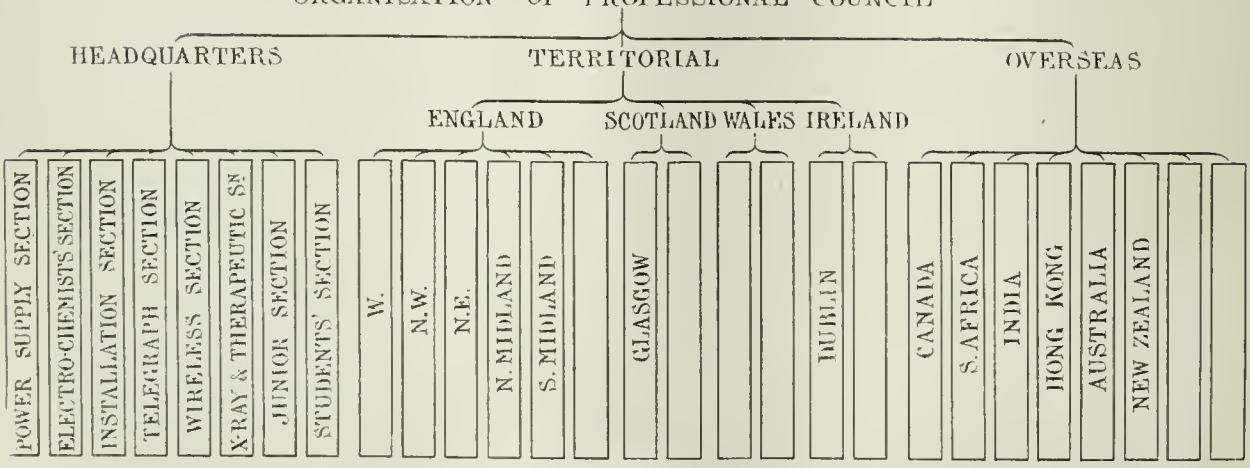


Diagram No. 3.

munity the Professional Council represents the whole of the members of the Electrical Industry in their individual capacity of Electrical Engineers irrespective of the branch to which they belong and for this reason the Professional Council should have a preponderating representation on the Grand Council.

### Constitution of Professional Council.

In view of the outstanding importance of the Professional Council its constitution calls for careful consideration. My proposals are shown diagrammatically in Diagram No. 2. First I would require that every member of this professional body should declare himself to belong to one particular branch of the Industry. He would have a perfectly free choice and for good cause shown could change his classification from time to time if desired. There would be practically no difficulty in this course; a man knows whether he is a manufacturer, a power station man, a consulting engineer, a professor or what not. On the Professional Council there would be a strictly proportionate representation of each of the groups under which it was decided to classify the Industry; the groups suggested are those shown in the diagram, i.e. Manufacturers; Power Supply Engineers including Railway and Tramway Engineers; Installation Engineers; Electro-Chemists; Telegraph Engineers including Submarine Cable Engineers; Wireless Engineers; Scientific Instrument Makers; Consulting Engineers; Scientific and Teaching and lastly Junior members. All these groups would be represented in proportion to the numbers in each group.

Now in the past whenever the Council of the Institution has made any attempt at proportional representation in that Council they have been met by one very serious difficulty which so far has never been overcome. You may arrange that every section of the Industry shall be represented at what I may call the General Election in May but the balance may be upset by the Chairmen of the Territorial Centres. I take it that in every case the man who is elected Chairman of a Centre is selected on his personal qualifications because he is the best man for the purpose in the district and in no way because he represents any particular interest. Now it seems to me that the following arrangement would get over the difficulty I have mentioned. Suppose we require that the Chairmen of the Territorial Centres should always be elected in January, that is to say well before what I call the General Election. It would then be known to what section of the industry they belonged and those sections would be required to take the Chairmen of the Territorial Centres as a portion of their representation. For example, suppose the manufacturers were entitled to send ten members to the Council at the general election and three Chairmen of Territorial Centres were manufacturers; the manufacturers would only be entitled to elect at the general election seven members.

### Organisation of Work of Professional Council.

So much then for the way in which the Professional Council would be elected. We have now to consider the organisation of its work. I wish to make quite clear before doing so that once having got the Professional Council elected on a representative basis the individual members work together as a whole and the work of the Council is subdivided by subjects and not by sectional interests. Again, unlike the other constituent councils in which each member is a delegate representing a firm in the case of the B.E.A.M.A. or the C.M.A. or a Company in the case of the Power Companies Association or a Corporation in the case of the I.M.E.A., each member of the Professional Council acts in his own personal capacity and carries on his work to the best of his judgment as an individual. The sub-division of the work of the Council which I suggest is based upon what is convenient for carrying that work on and in each of the branches of the work all interests are merged together, e.g. in a Territorial Centre no attempt is made to discriminate between manufacturing, power station, telegraphic and other interests; the work of the Council as affected by the particular district only is considered.

The organisation of the work of the Professional Council which I suggest is shown in Diagram No. 3.

The work falls broadly into three divisions of Headquarters, Territorial and Overseas.

The work of Headquarters would be looked after by a number of Committees dealing with the subjects shown in the diagram, and would be sectionalised on the lines I have indicated earlier in my address in speaking of the present Institution. There would be a Power Supply Section which would organise papers and discussions on Power Supply and allied subjects such as Railways, Tramways and Mining; an Electrochemistry Section dealing with furnace, electro-deposition and electro-chemical work generally; an Installation Section dealing with Wiring both ashore and afloat for lighting power and general purposes; a Telegraphic Section dealing with telephony and ordinary land and submarine telegraphy; a Wireless Section dealing with wireless telegraphy and allied subjects; a Therapeutic Section working in close association with the Royal Society of Medicine; a Junior Section looking after informal meetings and gatherings for the younger class of member and finally the Student Section. I do not say that all these Sections need necessarily be started in the first instance. I believe in conceiving a scheme upon the broadest and most extensive lines and then putting in force just so much of it as may be necessary at the time thus ensuring that all parts shall fit together and that the arrangements have not to be altered as time goes on. Though you may provide for developments that may never be required no harm ensues but if those developments are necessary they are made according to an ordered plan.

The Territorial Division would be divided broadly into England, Scotland, Wales and Ireland, England being sub-divided into Western, North Western, North Eastern, North Midland and South Midland. A blank is left in the diagram in certain cases not for any one Section but for as many as may become necessary in course of time; thus Scotland is divided into Glasgow space being left for further Centres and Wales might very well have several Sections later. Only Dublin

is shown for Ireland but there might well be a Section at Belfast also.

The Overseas Division would comprise Canada, South Africa, India, Hong Kong, Australia and New Zealand. Some blanks are left in this section for very obvious reasons.

### Conclusion.

Such, Gentlemen, in broad outline is the scheme of which I invite your discussion. It does not profess to be complete or perfect, it will require months of hard work by a competent committee to make it either perfect or complete but I think it is sufficiently detailed to enable you to express an opinion on its merits. Our Institution has in the past given every evidence of its vitality and willingness to adapt itself to developments. Everyone must admit I think that the industry has outgrown the present Institution and unless the latter be developed on much bolder and broader lines it will run serious danger of wilting and decaying.

In 1871 we were the Society of Telegraph Engineers. Twelve years later we developed into the Society of Telegraph Engineers and Electricians and in 1883 we became the Institution of Electrical Engineers. I submit, Gentlemen, that the time has now come when we should claim official recognition and seek to be known as the Royal Institute of British Electrical Engineers with a Royal Charter conferring on us the rights for which we ask.

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[Note.—In deference to established custom, the President did not give an Inaugural Address at the beginning of his second year of office and members resident in the vicinity of London will thus understand why the foregoing Address was delivered only at Territorial Centres. It is intended however that an opportunity shall be afforded of discussing the proposals in regard to the Charter at Headquarters as well as at every Territorial Centre.

Arrangements were made for the President to address members of the Irish Centre, the only one not visited, but the visit had to be deferred on account of the strike disturbances.]

# PROCEEDINGS OF THE INSTITUTION.

## 624th ORDINARY MEETING, 27 FEBRUARY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. Wordingham, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 20th February, 1919, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

*Benevolent Fund* :—H. Allcock, L. Andrews, A. Arnold, G. D. Aspland, Messrs. Babcock and Wilcox, Ltd., T. H. Banks, A. H. Bate, R. G. Beer, D. H. Bishop, R. A. R. Bottone, G. Bourne, W. Briggs, H. L. Brook, R. P. Brousson, W. E. Burnand, J. Burns, W. Burton, A. S. Butler, J. McL. Calder, A. Castello-Sosa, Colonel C. B. Clay, The Hon. E. Cozens-Hardy, J. R. Danson, G. L. Drury, W. Duncan, W. G. Edward, S. Evershed, H. Fawcett, A. H. Finlay, A. J. Fippard, A. P. M. Fleming, E. G. Fleming, C. R. Ford, C. L. Fortescue, H. Foulds, W. J. F. Freeland, W. A. Gillott, C. F. Goodale, E. T. Goslin, A. S. Gray, J. Hunter Gray, O. V. Greeves, J. E. Gripper, W. M. Haddow, R. C. Hall, A. S. Hampton, L. E. H. Harris, W. V. Haslam, C. E. Hawkins, C. M. Herbert, A. J. Hodgson, A. S. Hollin, R. H. F. Houstoun, H. G. Hughes, P. Hunter-Brown, S. Insull, Dr. G. Kapp, P. C. Kerr, W. T. Kerr, W. E. Kidner, J. E. Kingsbury, W. Kingsland, P. P. Kipping, H. L. Leach, M. A. Lebedeff-Lessin, A. Lindsay, P. McDermid, Professor J. T. MacGregor-Morris, A. C. McWhirter, A. Mears, A. J. Makower, C. H. Merz, A. T. K. Moir, W. M. Mordey, C. I. Morris, D. S. Munro, H. A. Nott, D. E. Nicolle, W. E. Nicoll, Lieut.-Col. W. A. J. O'Meara, H. Paterson, Q. H. Paterson, J. H. Pattman, N. Pemberton, F. H. Pernet, J. Plucknett, N. Prentice, J. H. Reyner, H. Rockey, H. N. Rodgers, C. D. Rogers, T. Roles, C. G. Saltren-Willett, F. H. Schroeder, W. H. Scott, G. H. Shortridge, G. M. S. Sichel, F. A. Simpson, H. A. Skelton, Sir W. Slingo, Major T. V. Smith, Sir John Snell, N. V. Snipe, T. F. Stent, J. H. Stephens, A. C. Stewart, C. D. Stoneham, J. P. Strange, Professor H. Stroud, A. J. Stubbs, H. W. Sullivan, J. H. Targett, Major A. M. Taylor, G. O. Tipping, T. H. Trice, S. H. Trippe, J. W. Turner, Professor M. Walker, E. J. Ward, W. H. Watling, T. F. Wells, J. W. Wheeler, J. H. Wild, H. D. Wilkinson, A. Willcock, F. H. Williams, N. J. Wilson, N. C. Woodfin, W. H. Woodhouse, C. H. Woodward, C. H. Wordingham, W. A. Wordley.

*Building Fund* :—Professor J. T. MacGregor-Morris and H. W. Young.

The President announced with regret the deaths of Mr. H. R. Constantine, Associate Member, Mr. C. H. Stearn, Member, Mr. E. O. Walker, Member, and Lieutenant Harold Hugh Hirst.

A paper by S. F. Barclay, Ph.D., Associate Member, and S. P. Smith, D.Sc., Member, entitled " The Determination of the Efficiency of the Turbo-Alternator " (see page 293) was read and discussed, and the meeting adjourned at 7.45 p.m.

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# THE NAVIGATIONAL MAGNETIC COMPASS CONSIDERED AS AN INSTRUMENT OF PRECISION.

By M. B. Field, O.B.E., Member.

(*Lecture delivered before* The Institution, 9 *January*, 1919.)

## SECTION I.

Some years ago I had occasion to discuss the subject of navigational compasses with a friend—a well-known member of this Institution—and after perhaps an hour's conversation, my friend remarked that he had no idea there was so much to be said about "the compass"; that he had pictured it as a nicely made magnetic needle attached to some sort of a card, the whole supported on a pivot and enclosed in some sort of a case. He had thought that such description adequately summed up, in brief, the mariner's compass.

It would be difficult to name any instrument of more ancient origin and yet of greater importance to civilization of all ages, and it is therefore a matter for no little surprise to find an almost universal neglect of the scientific consideration of the subject by students of physical science—in which category I must include electrical engineers.

I have heard it urged that such study is mainly one for the navigator—with this view I entirely disagree, and I venture to say that a comprehensive study of the problems involved in the mariner's compass of to-day forms, by itself, a far-reaching education in the application of scientific principles to intensely practical issues.

The problems involved are of great variety; we have, for example, problems of an essentially practical nature in mechanics and mechanical construction, the wear and tear of materials; the effects of vibrations; considerations of fluid friction, viscosity, and the motions of fluids; terrestrial magnetism; the magnetism of iron and steel, magnetic images, the fields of force and systems of magnetic potential due to complicated arrangements of magnets or the equivalent. We have even to touch upon problems in optics, the science of navigation, and the motions of heavenly bodies.

The title of this paper is the "Navigational Magnetic Compass considered as an Instrument of Precision," with special emphasis laid upon the word "Navigational."

Ordinarily, we expect a magnetic needle to tell us the direction of the magnetic force in the region in which it is placed.

If the field in question is the undisturbed field of the earth—undisturbed, except for the necessary local disturbance which the needle itself produces—we may expect any well-constructed and suitably supported needle to give us correctly the direction of the meridian.

Its precision will depend upon the accuracy of workmanship and freedom from pivot friction, and its error may be reduced to the same order as the error of unaided observation.

My friend's remarks were no doubt prompted by this conception of the functions of a compass.

Very much more is required of the navigational compass.

In the first place, we observe that the ship itself is magnetic, and that the magnetic force at any selected station not only differs in direction from the meridian, but, as the ship swings round, undergoes cyclic changes, both in magnitude and in direction.

On further investigation, we note that the amount of the deviation of the magnetic force from the plane of the meridian depends not only upon the course the ship may be steering at the time, but also upon her absolute geographical position.

Again, we find the ship's shape and proportions, the locality in which she was built, the direction of her head while under construction, in short, her past history, and particularly her recently past history, are all factors that influence her magnetic state.

Thus the duty we require the compass to perform is no easy one; surrounded as it is by disturbing

influences, we require it to ignore every misleading suggestion and to point unhesitatingly to the Magnetic North.

If we annul by magnets, or otherwise, the effect of all the magnetism of the ship, and this annulment remains effective on all courses, with the ship upright or listing, and at all parts of the earth, we obtain complete compensation; or again, if we neutralize the east-westerly component of the ship's magnetism, and the neutralization is effective under the above conditions, the compass is completely compensated.

In practice, we annul some of the components of the ship's magnetism, and neutralize the east-westerly force of others, in such a way that the compensation is very nearly complete on all courses, no matter whether the ship be upright or not, and the correction remains good at all parts of the earth—provided that the so-called permanent magnetism of the ship remains permanent, and that the so-called induced magnetism is strictly proportional to the inducing force and vanishes when the inducing force is withdrawn.

Unfortunately, we find that the permanent magnetism is not permanently "permanent," and the induced magnetism is not instantly "transient," and our complete compensation is to this extent incomplete.

Much of the permanent magnetism said to be "hammered" into the ship in the course of building is "shaken" out of her during her first few voyages, while magnetism of a semi-permanent character is "picked up" by a ship sailing for days together on a given course, and is only gradually lost, it may be over a period of hours, or even days, when the course is materially altered.

An example of this phenomenon, which caused the loss of the "Eastern Province," is related by Lord Kelvin in his article on "Terrestrial Magnetism"—Popular Lectures and Addresses, Vol. 3, page 257.

Further examples of permanent magnetism being "shaken" out of a newly built ship are furnished by the great change in the magnetic character of a new warship when undergoing gun-firing trials.

The precision of the navigational compass is therefore dependent not only upon the accuracy with which its "correctors" perform their function of compensating for the ship's normal magnetism, but also upon what Lord Kelvin called "unpredictable irregularities due to variations of the permanent magnetism, and to retention of some of the transient magnetism when the inducing influence is past."

The possible occurrence of unpredictable irregularities affords no ground whatsoever for relaxing our efforts to render the compass—apart from such irregularities—an instrument of precision, and it is in this sense that the term is used in the title of this lecture.

I need scarcely remind electrical engineers that no instrument—I care not of what type, or for what purpose—is altogether immune from unpredictable irregularities; and just as the painstaking observer is ever on the alert to detect an aberration, to measure its amount, and to trace its origin, so the careful navigator will be on the watch for changes of the magnetism of his ship, and will regularly avail himself of opportunities afforded of taking sun, moon, or star observations for the purpose of checking the readings of his compass.

The manner in which Lord Kelvin became intensely interested in the mariner's compass is characteristically told by him in his article on "Terrestrial Magnetism and the Mariner's Compass"—Popular Lectures and Addresses, Vol. 3. He began an article in *Good Words* in 1874, and after the historical portion of the subject had been dealt with the article stopped—to be continued only after five years. The interval had been devoted by Lord Kelvin largely to the subject upon which he started to write his popular article.

He says:—

"The first part of this article was written five years ago. I then thought I had a pleasant and easy task before me in the completion of it—to describe a scientific instrument which was known to the Chinese two thousand years before the dawn of science, and first used by them as a guide across the deserts of North-Eastern Asia; . . . But when I tried to write on the mariner's compass, I found that I did not know nearly enough about it. So I had to learn my subject. I have been learning it these five years, and still feel insufficiently prepared to enlighten the readers of *Good Words* upon it when I now resume the attempt to complete my old article."

When Lord Kelvin broke off his article in 1874, he had arrived at the conclusion that the mariner's compass, as used in iron ships, ought to be an instrument of precision, but was not, and he set himself the task of devising a new compass which might fairly lay claim to be an instrument of precision.

In concluding the article, Lord Kelvin described, in the simple and effective words of which he was such a master, the improvements in the construction of the mariner's compass and its accessory apparatus which he had devised during the intervening five years.

It is a notable fact that the instrument there described is, in all its essential scientific features, the standard instrument used by practically all the ocean-going liners of the present day, and such modifications as have been since introduced have, I think I may say in every case, to some extent sacrificed precision to some other advantage, either real or imaginary.

It cannot be disputed that the original Sir William Thomson model is a more accurate instrument than any of the forms of liquid compasses used to-day in the Navies of the world, and it is only necessary to study with sufficient insight the correction tables for different patterns of compasses, as given at the end of the most recent edition of the Admiralty Manual on the Deviation of the Compass, to obtain full confirmation of this statement.

In order that we may properly appreciate the requirements of the navigational compass of to-day, it is desirable to have before us at least a brief survey of the scientific development of the subject since the advent of the iron-built ship.

In 1839 Airy (later Sir George Airy), Astronomer Royal, wrote one of his many remarkable papers in the *Philosophical Transactions of the Royal Society*, on the deviations of the compass in iron-built ships, giving the interpretation of carefully conducted ex-

periments in the light of a mathematical theory—the whole investigation having been undertaken at the request of the British Admiralty. In the article, Airy propounded means for approximately correctly compensating a compass (with short enough needles, and small enough magnetic moment) for errors which arise due to the ship's magnetism.

Airy's practical method of compensation was a remarkable application to practical issues of an elaborate mathematical theory, and it was quickly adopted in the iron-built ships of the merchant service—but not so in the Admiralty. The Admiralty contented themselves with surveying the magnetic character of each ship from time to time, on the lines laid down by Airy, determining the deviations of the compass on various compass points, and representing these as a deviation diagram to be used by the navigator in determining his courses from the actual compass readings.

In 1856 Airy wrote a second paper in the *Philosophical Transactions*, in which he pointed out the disadvantage, and even the danger, of this procedure. He showed that the deviation diagram which was correct at one part of the earth was incorrect, and would lead to not inconsiderable errors, at another part of the earth where the value of H was materially different. The reason of this is that the needle assumes the position of equilibrium between (*a*) magnetic forces due to permanent magnetism of the ship (i.e. forces which do not depend on geographical position), (*b*) the force of the earth's field H, and (*c*) other forces proportional thereto, the amount of which depends on geographical position.

Airy pointed out that if the various magnetic forces, due to the ship, were properly neutralized by his method, leaving only the earth's horizontal field as the factor controlling the compass needle, the needle would indicate the true magnetic meridian at all geographical positions.

Acting probably on the advice of Airy, the Admiralty adopted the method of applying magnetic correctors to the compass.

Certain difficulties, however, arising from the use of magnetic correctors soon became manifest to expert compass adjusters, and it was found impossible in certain cases to obtain a correct compensation.

For example, the celebrated steamship, the "Great Eastern," was provided with a compass having an 11-inch needle, and after careful compensation in accordance with all the rules then laid down, very considerable errors were found when the ship's head occupied certain positions in azimuth.

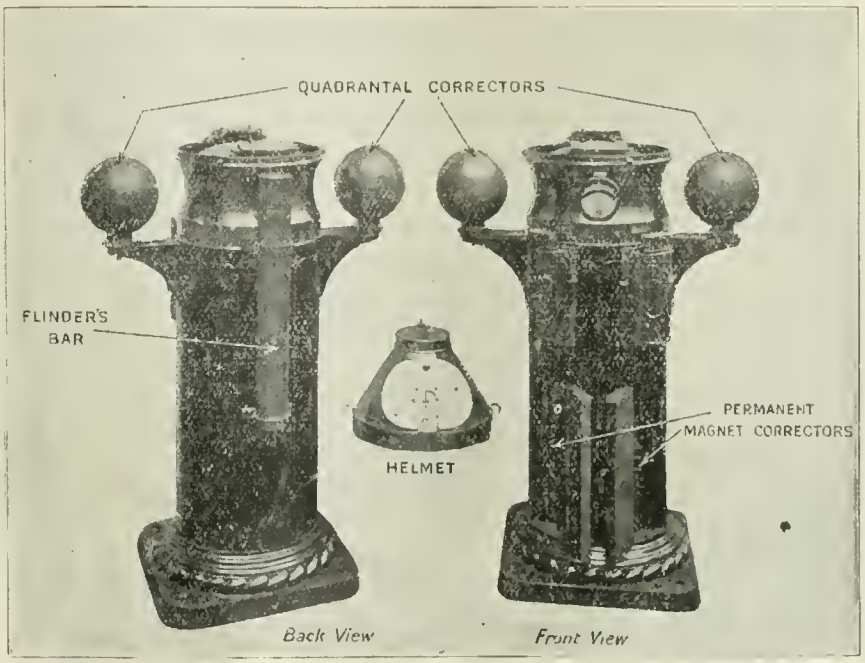



FIG. 1.—Compass binnacle, showing correcting devices.

As a matter of fact, errors of two kinds were being introduced by the design of compass employed, one depending upon the length of the needle, the other upon its magnetic moment.

This matter is of the greatest importance to us if we are to grasp fully the problem that, later on, Lord Kelvin set out to solve, and a digression at this stage appears advisable.

When selecting a suitable place for a compass station on board ship, due care is taken that the nearest iron is at a relatively great distance, so that if magnetized it gives rise to a magnetic field at the compass station which may be regarded as uniform over a region considerably larger than that swept out by the compass needles when rotated on the card pivot.

Moreover, the nearest iron must be sufficiently remote

to ensure that there is no sensible attraction of the needles due to magnetism induced in the iron by the needles.

When these conditions are duly observed, the position of equilibrium of the uncompensated card does not sensibly depend upon whether the needles be long or short, or whether their magnetic moment be large or small, but depends merely upon the direction of the resultant magnetic field acting at the compass station.

The compensation of the compass by Airy's method is effected by placing magnets and masses of iron near to the compass in positions calculated to produce magnetic forces in the region swept out by the card needles which exactly counterbalance the deviating forces due to the magnetism of the ship's ironwork.

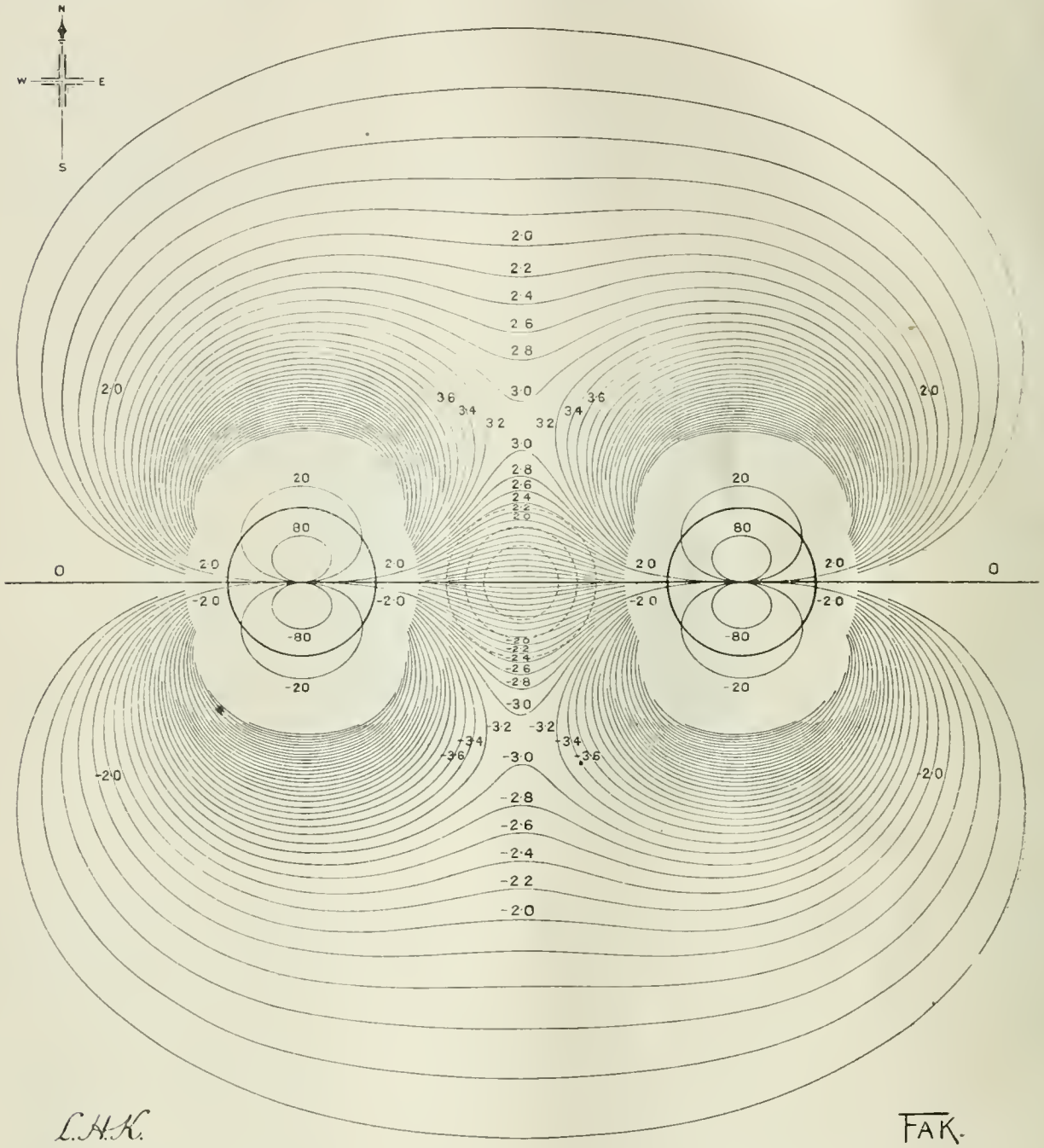



FIG. 2.—Intersection of equipotential surfaces with plane of compass card. Spheres E—W.

In order that the system may not become unwieldy and impracticable, it becomes necessary to place magnets and iron masses of considerable size very near to the compass; in fact, they are incorporated as part of the compass binnacle (see Fig. 1).

Now, the magnetic fields to which these give rise are by no means uniform over the region swept out by the needles of a long-needle card, with the result that a short needle will have a different position of equilibrium from that of a longer needle.

For example, it is usual to employ two cast-iron spheres attached to the binnacle for the correction of one of the effects of ship's magnetism, viz. the quadrantal effect.* These spheres may be of 8 inches diameter placed on either side of the compass at about 12 inches from the card centre, and level with the card. They become magnetized by the earth's field, or the resultant magnetic field acting in the region, and behave so far as external points are concerned as extremely short

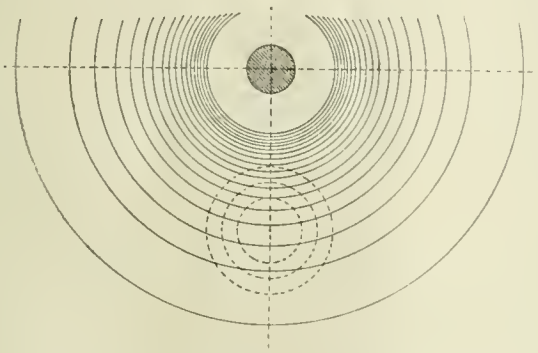


Fig. 3.—Equipotential lines due to Flinders' bar.

magnets of definite magnetic moment always pointing along the line of resultant magnetic force.

It is easy to draw the lines of magnetic force and lines of equal potential values due to such a system. The latter are exhibited in Fig. 2 for the case where the line joining the centres of the spheres is E–W (magnetic); it will be seen that these fields are very far from uniform. The dotted circles indicate the areas swept out by 4-inch, 6-inch and 8-inch compass needles respectively. A uniform field would be represented by a family of straight, parallel and equi-distant lines, while the equipotential lines would be a series of straight, parallel and equidistant lines at right angles to the former. We thus employ a non-uniform field, such as that shown in Fig. 2, to correct the compass for the deviation produced by a perfectly uniform field arising from some effect of ship's magnetism.

Again, another effect of ship's magnetism is compensated by what is termed the "Flinders' bar," a long, straight, vertical bar 3 inches in diameter, perhaps 16 inches long, and only 10 inches from the card centre, the upper end being usually level with the card.

* The quadrantal effect is due to magnetism induced in the ship's ironwork by the earth's force. It is manifested by a deviation which is alternately + and − in successive quadrants, hence its name. This effect is more fully dealt with later.

Such a bar becomes magnetized by the vertical component of the earth's field, and gives rise to lines of equal potential, as represented in Fig. 3—again a field of force very far from uniform.

Further, these correcting masses are sufficiently near for a needle of large magnetic moment to induce magnetic effects in the correctors, which, reacting upon the needle, will sensibly affect its position of equilibrium.

It is to be understood that the inductive effect of the needles on the iron correctors produces a mutual attraction which does not in any way depend on H. But when the compass is compensated by means of the correctors so as to read correctly on all courses at the place of adjustment, this inductive effect, which does not depend on H, is necessarily used to counteract, in part, an error due to a component of the ship's magnetism which does depend upon the value of H. The compensation is therefore only strictly accurate along lines on the earth's surface where H has the same value as at the place of adjustment.

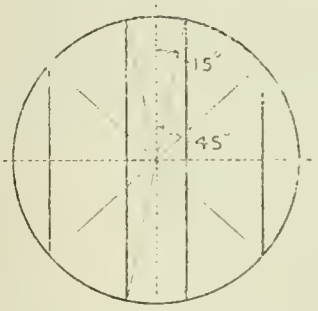



Fig. 4.—Standard Admiralty compass card.

We have then to remember that correctors, while introducing magnetic forces which neutralize those due to the ship, introduce additional forces which may produce deviations, depending on:—

(*a*) The length and arrangement of the magnetic needles.
(*b*) The magnetic moment of the needles.

In view of the difficulties experienced in the adjustment of the standard compass of the "Great Eastern," the errors which arise from the length and arrangement of the needles were carefully studied experimentally by Commander Evans, and mathematically by Archibald Smith, the results of the investigation being given in the combined paper in the *Philosophical Transactions*, 1861.

As a result of this investigation, the authors arrived at a remarkable discovery, namely, that with a certain arrangement of needles on a compass card, in place of a single needle, the errors due to length of needle very nearly disappeared, and that the particular arrangement necessary for the fulfilment of this condition was the very one which had been adopted in the construction of the standard Admiralty compass, entirely on account of other considerations.

The standard Admiralty compass card at that

date was provided with four needles arranged as in Fig. 4.

The object of this particular arrangement was to ensure that the moment of inertia of the system about all diameters was the same, a condition favourable to the elimination of what was termed "wobbly" motion of the card.

It had been observed by Smith, "that for this purpose (i.e. the elimination of 'wobbly' motion) with two uniform needles, it is necessary and sufficient that the ends of the needles should be separated by 60° of arc. The object is therefore obtained with two uniform needles, the extremities of which are 30° measured along the circumference of the card, from the extremities of the diameter which is parallel to them, and which needles are therefore chords of 60°, or with four uniform needles placed two and two with their extremities at equal distances (circumferentially) on each side of the chords of 60°."

The coincidence discovered mathematically and demonstrated experimentally by Smith and Evans, was that if the poles of the needles in the two-needle card subtend 60°, or in the four-needle card are placed at equal distances measured circumferentially from the extremities of the 60° chords, as, for example, in Fig. 4, the magnetic errors due to length of needle largely disappear.

I shall have many occasions to refer to Smith and Evans' work in this lecture, and I recommend those interested in the subject to study the original communication in the *Philosophical Transactions of the Royal Society*, 1861.

An interesting description of the Admiralty compass of this date by Commander Evans is to be found in the *Philosophical Transactions* of 1860, and the following is taken from the article in question :—

The needles were four in number, the inner ones being 7·3 inches long, the outer ones 5·3 inches long. They consisted of laminæ of clockspring placed vertically, and equidistant (circumferentially), being carried by a framework of brass screwed to the card. The weight of the system complete was 1,525 grains, say 100 grams nearly.

The card consisted of mica with paper cemented thereto.

The pivot was "native alloy" working in a ruby cup.

The azimuth circle was graduated to minutes of arc and the card to 20 minutes of arc.

The bowl was of stout copper, stated to be for the purpose of "calming vibrations."

It is very interesting to note that, in addition to the above-mentioned card, which was intended to be used in all ordinary weathers, a specially heavy card for stormy weather was provided, it being left to the navigator to unship the one and ship the other as occasion demanded.

This appears to have been the standard Admiralty compass from about 1840 to 1889, when it was replaced by Lord Kelvin's pattern.

It seems to have been left to Lord Kelvin to point out the true cure for unsteadiness.

For the purpose of producing steadiness, one naturally inclines to some method of fluid-friction damping, but for definite practical considerations, to be later discussed, Lord Kelvin dismissed the idea of fluid damping. He rather sought to render the card inherently stable under ordinary sea-going conditions.

The principal causes of unsteadiness have their origin in magnetic sources. The card is acted upon by the earth's vertical component in the manner of a dipping needle. The torque tending to tilt it about an E–W axis is V M, where V is the vertical force and M the magnetic moment. This torque is resisted by gravitational forces, equilibrium being established when the centre of gravity is displaced laterally from the vertical axis by a distance $r$, where $W r = V M$, W being the weight of the whole card.

We may therefore picture the system as a small mass corresponding to W at the end of a radius arm $r$.

As the ship rolls, this mass is subjected to accelerating forces, first in one direction and then in the other, and these form one of the principal causes of unsteadiness.

It is possible to neutralize the vertical component by means of an auxiliary magnet, but this again would introduce a new unsteadiness of the compass card in a seaway.

As stated, for rough weather conditions the Admiralty used a specially heavy card giving a longer period of oscillation and undoubtedly more pivot friction.

To overcome unsteadiness, we read of numerous instances of the mariner deliberately blunting the pivot, very much to the detriment of the compass as an instrument of precision.

Lord Kelvin recognized that the cure for this difficulty was only a matter of making the magnetic moment small and the period of oscillation sufficiently long—to attempt to absorb the energy of the card by solid friction at the pivot was naturally abhorrent to him. He recommended a period as high as 40 seconds, as against about 19 in the standard Admiralty good-weather card and about 26 in the ordinary merchant steamer compass.

To obtain the longer period, however, was not entirely easy; it involved a small magnetic moment, or a large moment of inertia, or both.

Now, the small magnetic moment, while advantageous on account of considerations already referred to, involved a small directive force on the card, while the large moment of inertia, if derived from the addition of mass, would inevitably imply additional pivot friction.

The problem was therefore to produce a card having a very large moment of inertia with a sufficiently small dead weight so that, with very weak and short needles, pivot friction would be negligible.

The other intensely practical considerations from the mariner's point of view were, as usual, prominently before Lord Kelvin. The card must stand rough handling, it should be capable of deformation and yielding to stresses, and of recovery without damage. It must stand the weather of all climates, intense heat and cold, prolonged dryness and humidity without warping, while the pivot, jewel, or even the card itself, must be capable of replacement at a moment's notice, in case of emergency, by spares usually provided with

the outfit; and this must be possible without liability of damage by a not very delicate-handed navigator under unfavourable conditions at sea.

I cannot do better than repeat here Lord Kelvin's own words:—

"The problem then of obtaining a compass which shall be steadier at sea, and shall also be better adapted for the perfect correction of the error due to the iron of an iron ship, or of cargo carried by the ship, requires—

"1. For steadiness a very long vibrational period with small frictional error.

"2. Short enough needles to allow the correction to be accurate on all courses of the ship for the place where the adjustment is made.

"3. Small enough magnetic moment of the needles to allow the correction of the quadrantal error to remain accurate to whatever part of the world the ship may go.

"This problem forced itself on me when I tried to write an article on the mariner's compass for *Good Words* five years ago, and hence it is that the article is not written until now. When there seemed a possibility of finding a compass which should fulfil the conditions of the problem, I felt it impossible complacently to describe compasses which perform their duty ill, or less well than might be, through not fulfilling these conditions."

Lord Kelvin then proceeds to describe his well-known compass card and compass.

Speaking of the card, he states that the weight of his design was one-seventeenth part of the weight of the ordinary 10-inch card hitherto in common use in the best-found merchant steamers, which was about 6 ounces. Further, that the magnetic moment was only about one-thirteenth part of that of the two needles of the ordinary 10-inch card as made at that date, and was so small that the error due to its inductive influence on the iron globes used for correcting the quadrantal error was practically insensible, even in such extreme cases as when the quadrantal error corrected amounted to 10° or 15°.

One feature of the card is perhaps of especial interest, showing how the minutest practical detail was studied by his master mind; and here again I will quote his words. He says:—

"The paper ring is cut across in 32 places, midway between the silk-thread spokes, to prevent it from warping the aluminium rim by the shrinkage it experiences when heated by the sun. Compass cards of the new kind made before this simple piece of engineering was applied to the structure, used to be perfectly flat in cloudy weather at sea, and to become warped into a saddle-shaped surface when the sun had shone brightly on them for a few minutes. Now with the radial cuts in the paper, the card may be first thoroughly moistened by the steam of a kettle, and then toasted before a hot fire, without in any sensible degree warping the aluminium rim or disturbing the degree of point divisions printed on the paper; and in its proper place under glass in its bowl, it remains quite undisturbed through all variations of temperature from coldest weather to hottest sun in actual sea-service."

It will be instructive to study the characteristics of a 10-inch dry card, as constructed for present-day use.

The card is somewhat heavier than that described by Lord Kelvin, principally on account of the addition of an opaque centre-piece, which has been found desirable with the system of illumination at present in vogue.

The weights are

| | |
|---|---|
| complete card | 12·83 grms |
| eight needles | 3·31 ,, |
| outer rim | 5·45 ,, |
| paper and silk spokes | 3·37 ,, |
| aluminium centre-piece | 0·70 ,, |

The moments of inertia are

| | |
|---|---|
| complete card | 1,207 grm.cm.² |
| eight needles | 58 ,, |
| outer rim | 877 ,, |
| paper and silk spokes | 272 ,, |
| aluminium centre-piece | — — |

It will be observed that while the rim represents only 42 per cent of the total weight, it contributes about 73 per cent of the whole moment of inertia, the approximate proportions of the different parts being as follows:—

| | Proportion of Whole Weight. Per cent | Proportion of Whole Moment of Inertia. Per cent |
|---|---|---|
| Needles | 25·8 | 4·8 |
| Outer rim | 42·4 | 72·7 |
| Paper and spokes | 26·3 | 22·5 |
| Centre-piece | 5·5 | — |

The magnetic moment of the needle system is of the order of 300 C.G.S. units, corresponding to a period of vibration (at Glasgow) of 32 seconds.

It is of interest to observe that the total number of lines of force passing through the central cross-section of the individual needles is approximately 90, corresponding to a value of B of about 7,500.

The individual needles have a polar strength of about 7 C.G.S. units.

The torque due to pivot friction of a good point and jewel cup, when the card is just coming to rest, is of the order of 0·25 dyne-centimetres.

### The Liquid or Spirit Compass.

The liquid or spirit-filled compass is undoubtedly favoured by some navigators on account of its extreme deadbeatness, especially for steering purposes. In small light craft it becomes a necessity in rough weather, and whenever space restrictions do not permit of the use of a 10-inch dry card the spirit compass should be resorted to.

This type, however, is far from perfect, and suffers from the following disadvantages:—

(1) It is very much overdamped; so much so, that the problem of the dry card is largely reversed.

In the liquid compass, oscillations are so much

damped that the main difficulty is to make it sufficiently quick or responsive in action.

To this end, undesirably great magnetic moments are usually employed.

(2) Trouble arises from leakage of the spirit and the formation of air bubbles.

(3) In cold weather, freezing may occur.

(4) The card with its heavy magnets and air-filled dome is extremely heavy. It must, however, be mounted upon its pivot in the workshop, and pivot and jewel must take their chance of being damaged in subsequent treatment, e.g. packing, railway transit, handling on board, etc. (The card of a dry compass is sent separately to the ship, and after the bowl is mounted in the binnacle on shipboard, the card is, as a last measure before adjustment, carefully placed upon its point.)

There is a fundamental difference between the liquid and dry card compass in the following respect: if the dry bowl be slowly rotated, as, for example, when a ship steers in a circular course, a torque can only be transmitted to the card by means of the solid friction effect at the pivot (air viscosity may be disregarded in this connection).

On rotation of the liquid compass, however, a drag is transmitted from the bowl to the card via the liquid, and if the edge of the card approach the sides of the bowl, this drag may be very large indeed.

It is no exaggeration to say that if a liquid compass having a large-diameter card the edge of which is brought near to the bowl (as is very frequently supplied for steering purposes) were mounted on a fast destroyer doing trials on the measured mile, and the vessel were to steam down the course, swing round at speed, and steam back, the card would be so disturbed by the turning motion that it would have hardly settled down to its true reading by the time the vessel was half way back along the course.

| Type of Card. | Diameter of Card | Maximum Length of Needle | Weight in Air | Moment of Inertia | Magnetic Moment | Time of Half Period at Glasgow |
|---|---|---|---|---|---|---|
| | In. | In. | Grams | C.G.S. | C.G.S. | Sec. |
| Kelvin 10-inch dry .. .. .. .. | 10 | $3\frac{1}{2}$ | 13 | 1,200 | 300 | 16 (in air) |
| Kelvin standard Naval liquid compass .. | $6\frac{1}{2}$ | $3\frac{3}{4}$ | 82 | 1,060 | 1,600 | 16 * |
| Ritchie .. .. .. .. .. .. | 9 | $7\frac{1}{4}$ | 152 | 3,270 | 5,160 | 20·5 * |
| Ritchie .. .. .. .. .. .. | $7\frac{1}{2}$ | $4\frac{1}{2}$ | 100 | 2,910 | 2,400 | 21 * |
| Common steering compass .. .. .. | 9 | 7 | 135 | 5,110 | 2,300 | 30 * |

N.B.—In the case of the liquid compass the card is deflected 45° and released; the time interval between the first and second transits of the N-point of card past the lubber line is called the half-period.

* In liquid 50 per cent alcohol, 50 per cent water at 20° C.

(5) A damaged card, jewel, or point cannot be replaced by the navigator on board. Replacement is essentially work for the instrument maker.

(6) The paint on the card and bowl interior is, in time, liable to be affected by the spirit, and the stronger the spirit, the greater will be the trouble from this cause.

(7) On account of the large magnetic moment and length of needles usually employed, the liquid compass is not susceptible of such complete and accurate compensation as the dry compass.

Other matters of minor though, nevertheless, of practical importance militate against the liquid compass; on the other hand, in certain instances, such as aeroplane, airship, submarine, torpedo boat, light high-speed craft, etc., no other form of magnetic compass seems possible.

Some idea of the strength of needles and the great masses employed in the cards of liquid compasses may be formed by a perusal of the above table, comparing a 10-inch Kelvin card (dry) with various makes of card for liquid compasses.

The effect of approaching the edge of the card to the sides of the bowl is shown by the following test:—

The bowl is mounted on a turntable which is rotated one complete revolution in about 60 seconds by clockwork. On completion of the revolution, the turntable is automatically stopped and the reading of the card observed. The card will have been dragged forward in the direction of rotation by the liquid, and will in time return to its position of static equilibrium. The number of degrees deviation due to the fluid drag is obtained by noting the final reading of the card after an interval of time sufficient for the fluid to become quiescent.

If the bowl be kept continuously rotating until the liquid has attained a steady state and the card be stationary (i.e. the drag be not so great as to pull the card over the E–W line), obviously the total torque mutually exerted between the walls of the bowl and

the fluid will be transmitted to the card and will produce a deviation determined by the relation :—

$$\text{Torque} = \text{H M} \sin\theta.$$

If, however, the bowl be given merely a transient rotatory motion, e.g. one revolution only, the torque exerted by the bowl walls does not immediately or entirely reach the card. On the other hand, the fluid motion is gradually propagated from the walls of the bowl inwards, it tends to become more or less uniformly distributed throughout the mass and gradually dies away. Thus, in the case of a rotatory impulse, a relatively small disturbance only will reach the card. If the bowl be very large, the disturbance reaching the card will be negligible (except under conditions of continuous rotation) and we have virtually the effect of the card surrounded by an "ocean of fluid."

This is the idea aimed at in the liquid bowl, viz. a card in an ocean of fluid. If the card be disturbed magnetically, its motions will be rapidly damped out, and it will be brought to rest, but if the bounding walls of the ocean be rotated by one complete revolution or less at moderate speed, the disturbance set up at the boundary walls will become evanescent before it reaches the card.

Of the liquid compasses above mentioned, the $6\frac{1}{2}$-inch card, Naval type, is undoubtedly the best. No larger card could, however, be attached without rendering it too sluggish, or, alternatively, necessitating a much larger magnetic moment.

I have tried a large variety of cards constructed for the purpose of reducing materially the moment of inertia of this pattern, fully expecting to obtain a quicker period. As a result, the period in air was considerably quickened, but in spirit no very marked difference was observable. This observation led to the conclusion that the main effect of inertia lay not in the card but in the liquid, that is to say, the effect of inertia of the liquid dragged round by the card was large in comparison with the inertia of the card itself. In other words, the problem is not analogous to that of a heavy body damped by fluid friction (i.e. by a retarding force on each unit of area proportional at every instant to the linear velocity) and the ordinary laws applying to this case are not applicable. We must, in fact, consider a double effect :—

(1) That of loading the card with an apparent additional moment of inertia ; and
(2) A retarding force on each unit of area proportional at every instant to the linear velocity.

Suppose, for example, we impart to a disc, e.g. a compass card, an angular velocity $\omega_0$ about its axis, and we load the disc with an extra moment of inertia $I_1$, the torque that must be applied to the disc to overcome the additional inertia is $I_1 \frac{d\omega_0}{dt}$.

If, further, a true fluid-friction act upon the disc, such that $k$ is the tangential drag on unit area when moving with unit velocity, the torque that must be applied to the disc to overcome fluid friction drag is $2 I_s k \omega_0$, $I_s$ being the moment of area of one side of the disc.

Hence, the total torque which must be applied to overcome the effects of additional inertia and fluid friction is

$$I_1 \frac{d\omega_0}{dt} + 2 I_s k \omega_0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

We will compare this expression with that applying to the oscillation of a light disc in a viscous fluid.

Reference may be made to Clerk Maxwell's measurements of the viscosity of air, etc., by observations of the decrement of the angle of oscillation of a series of light discs supported on a torsion ligament. The oscillating discs were disposed intermediate between a series of stationary discs, the surrounding medium being air or other fluid to be experimented upon.

A description of the experiments and the mathematical theory of the same is to be found in Clerk Maxwell's "Collected Papers," Vol. 2, page 1.

I propose to consider the problem here in its simplest form.

We shall consider a disc immersed in a viscous fluid, maintained in harmonic oscillation about its principal axis (normal to the plane of the disc), we shall neglect edge effects, and we shall consider only the tangential flow in the fluid—i.e. we shall ignore, as Maxwell did,* any radial flow.

While these conditions are not strictly applicable to a liquid compass card, we are enabled to form an approximate working notion of what occurs.

Let the motion of the disc be represented by

$$\theta = A \cos nt \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Let $\mu$ be the coefficient of viscosity of the fluid,
$\rho$ ,, density of the fluid,
$x$ ,, distance measured axially from the disc to any point of the fluid,
$I_s$ ,, moment of area of one surface of the disc,
$\omega$ ,, angular velocity of any small element of the fluid,

then it is easy to show that the fluid motion must be subject to the law †

$$\mu \frac{d^2\omega}{dx^2} = \rho \frac{d\omega}{dt} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

At the disc, that is when $x=0$, the fluid has the same motion as the disc itself, while at an infinite distance the fluid is quiescent, and the solution which satisfies these particular boundary conditions, viz.

(a) when $x=0$, $\theta = A \cos nt$,
(b) when $x=\infty$, the fluid is quiescent,

is
$$\omega = -nA\epsilon^{-px} \sin(nt - px)$$
where
$$p = \sqrt{(\tfrac{1}{2}\rho n/\mu)} \quad . \quad . \quad . \quad (4)$$

* See "Liquid Friction," by Professor John Perry, F.R.S., *Philosophical Magazine*, 1893, p. 443.
† See Clerk Maxwell's paper already referred to.

The fluid reacts upon the disc, producing a torque represented by

$$2\,I_s\,\mu\left(\frac{d\,\omega}{d\,x}\right)_{x=0}$$

or

$$I_s\sqrt{(2\,\rho\,\mu/n)}\;n^2\,A\cos n\,t+2\,I_s\sqrt{(\tfrac{1}{2}\,\rho\,\mu\,n)}\;n\,A\sin n\,t\quad .\quad (5)$$

Now $$n^2\,A\cos n\,t=-\frac{d\,\omega_0}{d\,t},$$

while $$n\,A\sin n\,t=-\omega_0.$$

Hence (5) may be written in the form :—

$$-\left[I_s\sqrt{\left(\frac{2\,\rho\,\mu}{n}\right)}\left(\frac{d\,\omega_0}{d\,t}\right)+2\,I_s\sqrt{\left(\frac{\rho\,\mu\,n}{2}\right)}\,\omega_0\right]\qquad (6)$$

and if we compare this with (1), we see that the effect of the liquid is as if

(1) a moment of inertia $I_1$ had been added such that $I_1=I_s\sqrt{(2\,\rho\,\mu/n)}$, and
(2) the disc were retarded by fluid friction of which the coefficient $k$ were equal to $\sqrt{(\frac{1}{2}\,\rho\,\mu\,n)}$.

We can now see what thickness of fluid layer, if oscillating solidly with the disc, would represent the additional moment of inertia.

If $d$ be the thickness of the layer, then

$$I_s\,\rho\,d=I_s\sqrt{(2\,\rho\,\mu/n)},$$

or $$d=\sqrt{(2\,\mu/\rho\,n)}=1/p.$$

Applying this result to a practical case, we have the following :—

$\mu$ for mixture of water and alcohol containing 50 per cent by weight of the latter, at 15° C.=0·033 C.G.S. units,
$\rho$=0·92, and if the time of a complete period be 30 sec., $n=2\,\pi/30=0{\cdot}209$,

hence $$d=0{\cdot}586\text{ cm.}$$

We are therefore loading the disc with the equivalent of a layer of liquid 5·86 mm. in thickness.

Now, the mica card of a liquid compass of the standard Naval pattern may be taken as approximately 0·2 mm. thickness, while its specific gravity is 2·6; hence the effective additional moment of inertia in this case is of the order of 10 times that of the mica card itself.

It is to be noted that the longer the period, the greater is the effective added moment of inertia, since $d\propto 1/\sqrt{n}$.

Further, we see that the moment of inertia is proportional to $\sqrt{(\rho\,\mu)}$, so that in order to reduce it as far as possible we require a liquid of small density and small viscosity.

Suppose, for example, we substitute for the water-alcohol mixture one of the paraffin series for which $\mu$=0·0033 C.G.S. units, and $\rho$=0·75. We have $d$=0·205 cm. and the moment of inertia is reduced to about 3 times that of the mica card.

It will thus be appreciated that the selection of a suitable fluid for the liquid compass is an all-important matter.

The usual fluid employed is a solution of alcohol in water, the strength of the solution depending upon the lowness of temperature to which the bowl is likely to be subjected.

The curves in Fig. 5 represent the viscosity in C.G.S. units of various strengths of water-alcohol solutions at various temperatures.

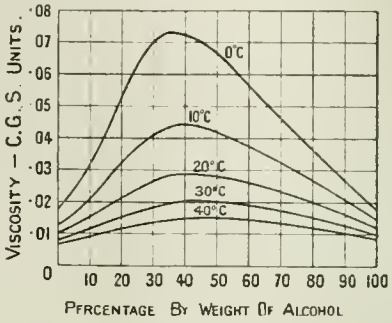



Fig. 5.—Viscosity of water-alcohol solutions.

The ideal fluid is hard to find; it should fulfil the following conditions :—

(1) The viscosity should not be greater than 0·003.
(2) The density should not be greater than 0·75.
(3) The viscosity and density should not vary much over an ordinary range of temperature.
(4) It should stand temperatures down to −50° C. without freezing or becoming thick.
(5) It should stand temperatures up to, say, 60° C. without flashing.
(6) It must be clear, colourless, and inert as regards metals, paints, and cements.
(7) It should be not readily inflammable, non-poisonous, and inexpensive.

I have been unable to obtain a fluid combining all these properties, but it is not difficult to find one which provides a far better compass-filling than the usual water-alcohol mixture.

Returning to the consideration of the fluid motion, we see from Equation (4) that the angular displacement of a particle follows the law

$$A\,\varepsilon^{-p\,x}\cos(n\,t-p\,x),$$

which implies that the motion is stratified, and that each successive stratum of the fluid, as one travels axially from the disc, oscillates with a diminishing amplitude and an increasing phase displacement. This action is accompanied by an absorption of energy due to the shearing action that takes place throughout the liquid.

The maximum displacement of the successive layers of the fluid is represented by the logarithmic curve of which the law is

$$y=A\,\varepsilon^{-p\,x}.$$

Again, the torque exerted on, say, the lower side of any stratum, due to the drag of the fluid immediately below, is proportional to $\mu\,(d\,\omega/d\,x)$, the value of which is readily obtained from Equation (4).

If now for any given value of $x$ we find the value of $d\omega/dx$ very small compared with its value when $x=0$, we conclude that if a fixed boundary plane were located at this distance, the fluid drag upon it when the disc was maintained in oscillation would be a very small fraction of the drag reacting on the card; and, conversely, if the boundary plane received an oscillatory motion of the same character (the disc being stationary) the fluid drag which would reach the disc would be correspondingly small.

In other words, in so far as oscillatory motion of the stated frequency was concerned, we might regard the disc as being immersed in an "ocean of fluid."

The maximum value of the drag on any stratum due to the fluid below is proportional to

$$\mu\, n\, p\, A\, \varepsilon^{-px}.$$

If we take $p=1{\cdot}7$ [$d=0{\cdot}586$] the curve represented by $y=\varepsilon^{-px}$ is that shown in Fig. 6, from which we see that at a distance of 1 cm. the drag has decreased to 0·183 times its value at the disc.

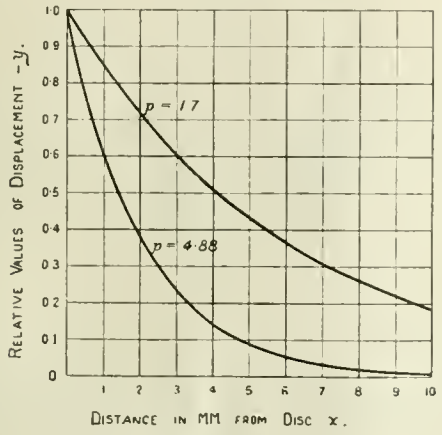



FIG. 6.

If, however, $p=4{\cdot}88$ ($d=0{\cdot}205$) at a distance of 1 cm., the drag is reduced to less than one-hundredth part of its value at the disc.

The above again emphasizes the advantage obtained from the choice of a fluid having a small value of $\mu$, and further, we see that for such values of $p$, if the fluid extend only a few centimetres from the disc, for all practical purposes we can regard it as an "ocean" of fluid.

It will be observed that the problem we are considering is strictly analogous to the penetration of eddy currents set up in an infinite slab of conducting material of constant magnetic permeability, bounded by a plane surface, when an alternating magnetic force is applied at the plane surface in some direction coincident with the plane.

Reference may be made to my communication to Volume 33 of the *Journal*, entitled "Eddy Currents in Solid and Laminated Masses."

The oscillatory motion of the successive fluid strata, with diminishing amplitude and increasing phase displacement, is a case of diffusion, or regarding it as a wave propagated axially from the disc which becomes rapidly evanescent, we may say that the wave-length

$$\lambda=2\,\pi/p \text{ cm.},$$

and the apparent axial velocity of propagation is

$$\frac{n\,\lambda}{2\,\pi}=\frac{n}{p} \text{ cm. per second.}$$

If we take the time of an oscillation as 30 seconds and the fluid to be a mixture of alcohol and water, we may take $p=1{\cdot}7$; hence we obtain $\lambda=3{\cdot}7$ cm., and the velocity of propagation $=0{\cdot}12$ cm. per second.

The following comparison between a compass constructed for a specially low viscosity fluid and the standard Naval pattern of compass is of very great interest in this connection.

| | Standard Naval Compass | Low Viscosity Compass |
|---|---|---|
| Diameter of card .. .. | 6·5 inches | 6·5 inches |
| Weight of moving system .. | 82 grms. | 37 grms. |
| Moment of inertia of moving system .. .. .. | 1,060 C.G.S. | 550 C.G.S. |
| Magnetic moment .. .. | 1,600 ,, | 970 ,, |
| Weight of magnets .. .. | 28 grms. | 22 grms. |
| Period in air .. .. | 13 sec. | 12 sec. |
| Half-period in liquid .. | 16 ,, | 11·5 sec. |
| Carry-past after 1 rev. in one minute .. .. | 4° | 1° |

It will be observed that on all points the low viscosity compass shows to advantage.

The "loading" of a disc of 6½ inches diameter when maintained in oscillation with a period of 30 seconds in a water-alcohol medium of the particulars previously given, is equivalent to a layer of fluid 0·586 cm. thick. The moment of inertia of such layer is 3,040 C.G.S. or 3·7 times that of the standard Naval compass card.

### The Distribution of the Magnetism of a Compass Needle, and a Brief Explanation of the Smith-Evans 60° System.

I must preface my explanation by defining the sense in which I shall hereafter use the expressions:

Pole, or poles of a magnet,
Polar strength,
Distance between poles, or polar length of magnets, and
Magnetic moment,

since these terms are variously and unsatisfactorily defined in different textbooks.

We will confine our attention to magnets which are geometrically and magnetically symmetrical about their central plane, having Northern magnetism distributed over one half, and Southern magnetism over the other half. That is to say, for the present purpose,

in order to simplify our conceptions, we may exclude unnecessary complications such as consequent poles, dissymmetry of magnetism, and so forth.

In Fig. 7, A B is a magnetic needle, C the central plane.

Imagine a number of transverse planes to divide the magnet into a large number of elements, and imagine the magnet to be placed in a uniform field of unit intensity (i.e. a field conventionally represented by one line of force per square centimetre) directed at right angles to the length of the magnet.

Each individual element will experience a force in the direction of the uniform field, which force can, in fact, be separately measured, as hereafter explained.

The sum of all such forces from B to C, measured in C.G.S. units, is the "polar strength."

It must of necessity be equal and of opposite sign to the sum of all such forces from A to C, as otherwise the apparent weight of the magnet, when weighed in the earth's field, would depend on its magnetic state, which is contrary to all experience.

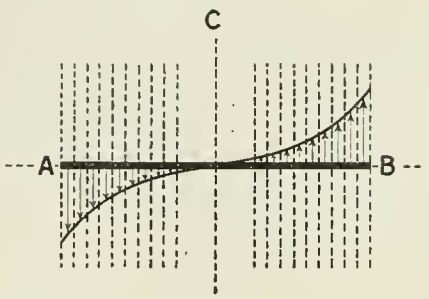



FIG. 7.

The magnetic moment is the mechanical couple, expressed in C.G.S. units, experienced by the magnet when normal to the uniform field of unit intensity. This definition is consistent with the expression for the period of vibration of the magnet when freely suspended in a uniform field (the arc of vibration being small), viz.

$$\tau = 2\pi\sqrt{\left(\frac{I}{H\,M}\right)},$$

where $\tau$ is the vibrational period in seconds,

H = strength of the uniform field in C.G.S. measure,

I = moment of inertia of the vibrating system about its centre of oscillation, in C.G.S. units, and

M = magnetic moment as defined above.

If we imagine located at the centre of each element a small mass whose weight is numerically equal to the force experienced by that element, the sum of all forces acting from B to C will be numerically equal to the weight of all the little elements of mass added, and the point of application of the resultant force will be the centre of gravity of all the elements of mass.

The positions of the centres of gravity of the mass elements, or of the "magnetic distributions" taken over each half of the magnet, are the "poles," and their distance apart is the "polar length of the magnet."

On this basis, we are justified in making use of the highly artificial conception of magnetic matter (positive or negative as the case may be) distributed over the surface or throughout the volume of each element of the length of the needle, the amount of magnetic matter being numerically equal to the force experienced by such element when the magnet is placed in the uniform field of unit intensity.

We may say that the magnet behaves in a uniform field as if the Northern magnetism were concentrated at the centre of gravity of the Northern magnetic matter, and the Southern magnetism at the centre of gravity of the Southern magnetic matter, while the magnetic moment, as defined above, may be otherwise expressed as the amount of Northern or Southern magnetic matter multiplied by the distance between the two centres of gravity.

We may even go further and picture to ourselves a specially constructed balance for "weighing" the amount of magnetic matter.

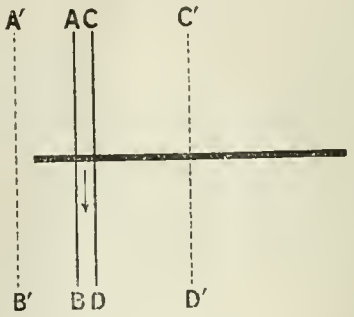



FIG. 8.

Suppose in Fig. 8 A B and C D be two vertical and parallel infinite current sheets at right angles to the plane of the paper, i.e. infinite both in the A B direction and in the direction normal to the paper. Suppose the current in these sheets be flowing at right angles to the plane of the diagram, so that in A B it is directed away from the reader, and in C D it is directed towards him. Let the current per centimetre length measured along A B and C D be $c$; then there will be a uniform field directed vertically downwards between the current sheets, whose value is $4\pi c$, and there will be no field to the left of A B or to the right of C D.

If we make $c$ have the value of $1/(4\pi)$ C.G.S. units, the field between the current sheets will have unit intensity in C.G.S. measure, i.e. a density of one line per square centimetre.

Imagine, further, a narrow and short vertical slot cut in the current sheets through which passes a magnetic needle slung on one arm of a weighing balance, the gravitational weight of the needle being just balanced when the current in each sheet is zero. Then on adjusting the current $c$ to the value $1/(4\pi)$ C.G.S. units, or the field strength to unit intensity, we could, in effect, *weigh* the amount of magnetic matter contained on or in that portion of the needle between the current sheets.

If we take the weight in grammes, and multiply by 981 (the force, in dynes, of gravity on one gramme

mass), we obtain the amount of magnetic matter in C.G.S. units.

Or again, if we separate the current sheets so that one-half of the needle lies between them (Fig. 8), the central plane of the needle coinciding with the current sheet C′ D′, we "weigh" the total magnetic matter of one-half of the magnet

A balance for "weighing" the magnetic matter on a given portion of a small straight needle is represented conventionally in Fig. 9.

If it were not for the fact that the lines of gravitational force were all sensibly parallel and the field of force uniform over any limited region in which we can experiment, we should not be able to deal with centres of gravity in the usual way, and many of our simple mechanical problems would become extremely complex.

Fortunately, this difficulty does not arise in this region of physics, but it does arise in dealing with magnetic needles in non-uniform fields of force.

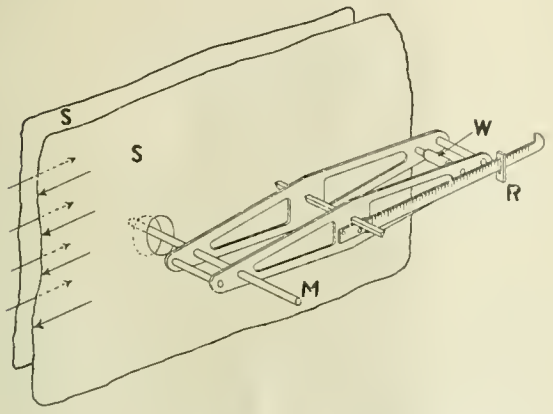



FIG. 9.—Conventional Representation of Magnetic Balance.

S, S = current sheets, current flow in direction of arrows.
M = magnetic needle under survey.
W = counterbalance weight.
R = rider.

Direction of magnetic field between current sheets is vertical.

In a non-uniform field, e.g. that produced by the end of another magnet in the neighbourhood, the needle does not behave as if the + and − magnetic matter were concentrated at any two points, and, conversely, the magnetic force of the needle at an external point cannot strictly be determined on the assumption of the existence of centres of magnetic force anywhere in the needle.

If, however, the external point be not too near (in relation to the dimensions of the needle), the error in assuming that the force is the same as if the magnetism were concentrated at the poles is not great, and it is convenient to make this assumption, investigating separately the order of error introduced by the false hypothesis.

For the present, therefore, I consider the magnet as behaving as though its magnetism were concentrated at "the poles," as defined.

Let us now consider a compass needle on board ship. Let the polar length of the needle be $2a$, let O be the centre of oscillation, and let O C be the direction of the magnetic force of a uniform field produced by the ship's permanent magnetism.

The direction of the magnetic force makes the angle $\zeta$ with the magnetic axis of the needle (see Fig. 10).

If H′ be the value of the magnetic force, the component normal to the length of the needle is $H' \sin \zeta$.

If the needle be magnetically symmetrical, and if $m$ be the polar strength, the torque on the needle will be $2\,a\,m\,H' \sin \zeta$.

As the ship swings, the angle $\zeta$ varies, and the above expression gives the value of the torque for any direction of the ship's head, provided $\zeta$, the angle between the magnetic axis of the needle and the direction of the field H′, be known.

If instead of considering the effect of the uniform field of H′ lines per square centimetre, we consider a single magnetic pole of strength $m'$, such as the end of a corrector magnet placed at $b$, $\zeta$, in the plane of the card, we see that, the needle being no longer in a uniform field, the above expression for the torque does not apply.

The torque will, however, be proportional to $m$ and $m'$, and will depend on $a$, $b$, and $\zeta$; there is no other factor that can enter into consideration.

As the ship swings, $\zeta$ will be the only variable; the corrector magnet being fixed to the ship, $b$ will be constant. We may therefore say that the torque experienced by the needle is a function of $\zeta$.

Furthermore, the torque will obviously have the same value for angles $\zeta$, $\zeta+2\pi$, $\zeta+4\pi$, etc., and the expression for the torque will therefore be periodic; in other words, the torque may be expressed as a series involving the sines and cosines of $\zeta$ and multiples of $\zeta$.

Considerations of symmetry will indicate, however, that the more general series above indicated simplifies to one containing only terms involving sines of odd multiples of $\zeta$, and hence that the torque may be written in the form

$$T = 2\,m'\,m\,[A_1 \sin \zeta + A_3 \sin 3\,\zeta + A_5 \sin 5\,\zeta + \text{etc.}] \quad . \quad (7)$$

where A, $A_3$, $A_5$, etc., depend on the values of $a$ and $b$ only.

Smith showed that the importance of these various effects depends on the ratio of $a/b$, the following values being approximations:—

$$\left.\begin{aligned} A_1 &= \frac{a}{b^2}\left[1 + \frac{3\,a^2}{8\,b^2} + \frac{15\,a^4}{64\,b^4}\right] \\ A_3 &= \frac{a}{b^2}\left[\frac{15\,a^2}{8\,b^2} + \frac{105\,a^4}{128\,b^4}\right] \\ A_5 &= \frac{a}{b^2}\left[\frac{315\,a^4}{128\,b^4}\right] \end{aligned}\right\} \quad . \quad . \quad . \quad (8)$$

If, now, the corrector $m'$ be used to compensate for the effect of H′, we could make $m'$ numerically equal to $a\,H'/A_1$, in which case we should have neutralized the effect H′ of the ship's magnetism by introducing the corrector $m'$, but we should have introduced additional effects represented by $A_3 \sin 3\,\zeta$, $A_5 \sin 5\,\zeta$, and so on.

A term such as $\sin \zeta$ is known as a semicircular

effect, since its effect is positive in one semicircle and negative in the other semicircle, sin 3 $\zeta$ as a sextantal effect, sin 5 $\zeta$ as a decantal effect, and so forth, so that we may say we have wiped out the semicircular effect of H′ at the expense of introducing sextantal and other complications.

If the needle be short, so that $a^2/b^2$ is negligible in comparison with unity, $A_3$ and $A_5$ become negligible, and the sextantal and decantal terms may safely be disregarded, in spite of the fact that $m'$ does not give rise to a uniform field.

The obvious meaning of this is that if we confine our attention to a sufficiently small region, or make

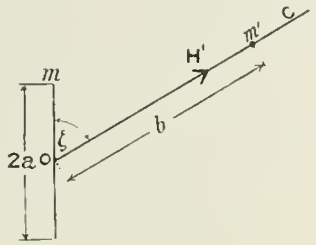



Fig. 10.

$a$ so small that the region swept out by the needles is sufficiently restricted, we may consider the field due to $m'$, within the confines of this limited region, to be uniform.

The question then arises, if $a$ be not very small, can we by any arrangement of the needles make the coefficients $A_3$, $A_5$, etc., vanish ?

Suppose the single needle be replaced by two parallel needles, whose similar poles subtend the angle $2\alpha$ at the centre, $2a$ now being the diameter of the circle of which the needles form chords.

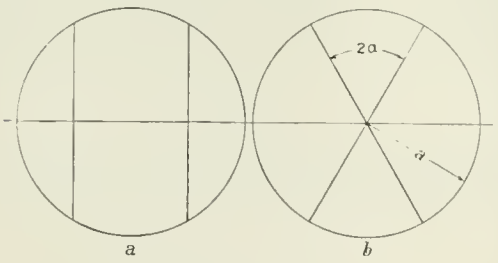



Fig. 11.

Such an arrangement is indicated in Fig. 11 (*a*). This arrangement is magnetically equivalent to the arrangement shown in Fig. 11 (*b*) ; we assume that the two needles are identical and magnetically symmetrical.

We can find the value of T for this compound needle by successively substituting for $\zeta$ in (7) the values $(\zeta+\alpha)$ and $(\zeta-\alpha)$ and adding.

The general term in expression (7), say $A_n \sin n\zeta$, then becomes

$$A_n [\sin n(\zeta+\alpha)+\sin n(\zeta-\alpha)] = 2\cos n\alpha\,[A_n \sin n\zeta] \quad (9)$$

and if we choose $\alpha$ so that $n\alpha=\frac{1}{2}\pi$, this term vanishes from the series ; thus if $\alpha=30°$ the sextantal term vanishes.

This being the most important term to eliminate, the needles of a two-needle card should apparently be so arranged that their poles subtend an angle of 60° at the centre.

If we extend the argument to a four-needle card, of which the similar poles of the longer needles subtend the angle $2\alpha_1$ and the similar poles of the two shorter needles subtend the angle $2\alpha_2$, and all the needles are symmetrical and *have the same polar strength*, we have to substitute for $\zeta$ in (7) successively the values

$$(\zeta+\alpha_1),\ (\zeta-\alpha_1),\ (\zeta+\alpha_2) \text{ and } (\zeta-\alpha_2),$$

and add, when the general term in (7) becomes

$$4\cos n[\tfrac{1}{2}(\alpha_1+\alpha_2)]\cos n[\tfrac{1}{2}(\alpha_1-\alpha_2)]\{A_n \sin n\zeta\} \quad (10)$$

If now we make

$$\tfrac{1}{2} n_1(\alpha_1+\alpha_2)=\tfrac{1}{2}\pi,$$

and/or

$$\tfrac{1}{2} n_2(\alpha_1-\alpha_2)=\tfrac{1}{2}\pi,$$

one or two terms vanish ; hence if

$$(3/2)(\alpha_1+\alpha_2)=\tfrac{1}{2}\pi, \text{ and}$$
$$(5/2)(\alpha_1-\alpha_2)=\tfrac{1}{2}\pi,$$

or $\alpha_1=48°$ and $\alpha_2=12°$

both sextantal and decantal terms vanish.

If, however, $(3/2)(\alpha_1+\alpha_2)=\frac{1}{2}\pi$ only, the sextantal term vanishes, but not the decantal.

It will be observed that the Admiralty compass, as shown in Fig. 4, approximately conformed to this condition, viz. $(3/2)(\alpha_1+\alpha_2)=\frac{1}{2}\pi$, but, as already stated, the disposition of the needles was dictated by considerations of moment of inertia rather than by the peculiar magnetic characteristics obtainable therefrom.

The foregoing theory presupposes :—

(1) That the magnetism of the needles can be considered as concentrated at the poles.
(2) That the location of the poles is known.
(3) That the needles are symmetrically magnetized and of the same pole-strength ; and it must be further assumed—
(4) That no change of distribution, or of relative strength, takes place subsequently.

We may, however, extend the theory and very briefly consider the effect of distributed magnetism.

First, we will take the case of a single needle symmetrically magnetized.

Assume the density of magnetic matter at a point $x$ cm. from the pivotal axis to be $\rho_x$, $\rho_x$ being a function of $x$, so that the amount of magnetic matter contained in an element of length $(\delta x)$ of the needle is $\rho_x \delta x$.

If, then, we consider two such elements located at $+x$ and $-x$ respectively, we can apply Equations (7) and (8) to obtain the torque due to two such elements, if we substitute $x$ for $a$, and $\rho_x \delta x$ for $m$.

To obtain the torque on the whole needle, we require to determine the summation of the torques on all such elements (taken in pairs).

A little consideration will suffice to show that we may still write T in the form given in (7) if we modify (8) by inserting $a_2^2$ for $a^2$, and $a_4^4$ for $a^4$ where

$$a_2^2=\frac{\Sigma\, x^3\, \rho_x\, \delta\, x}{a\, m} \quad \text{and} \quad a_4^4=\frac{\Sigma\, x^5\, \rho_x\, \delta\, x}{a\, m},*$$

the summation being extended over the range from $x$=half length of needle to $x$=0.

The expression for $A_1$ then becomes

$$A_1=\frac{a}{b^2}\left[1+\frac{3\,a_2^2}{8\,b^2}+\frac{15\,a_4^4}{64\,b^4}\right],$$

and so on.

If the magnetism were concentrated at the poles, we should have $a=a_2=a_4$; the length $a$ determines the distance measured from the pivotal axis to the poles; $a_2$ and $a_4$ are lengths as above defined which determine the loci of certain points, which for the want of better terms I will call the "$p_2$" and "$p_4$" points of the magnetic distribution.

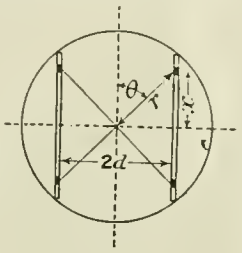



FIG. 12.

If we experimentally determine the distribution in the manner hereafter described, we can ascertain the values of $a_2$ and $a_4$ and thus arrive at the magnitude of the sextantal term, etc., with greater precision.

Secondly, in the case of a compound needle (two needles), let us consider four elements, two on each needle, situated at $+x$ and $-x$ respectively.

The sextantal term for these four elements will be, see expressions (7) and (9), and Fig. 12,

$$4\, m'\, [\rho_x\, \delta\, x]\, A_3 \cos 3\,\theta \sin 3\,\zeta,$$

where $r$ in the diagram replaces $a$ in the expression for $A_3$.

If we neglect the term in $r^5/b^5$ as unimportant, we may say the sextantal term vanishes

if $$\Sigma\left\{[\rho_x\, \delta\, x]\, r^3 \cos 3\,\theta\right\}=0,$$

or if $$\Sigma\left\{(x^3-3\,x\,d^2)\,\rho_x\, d\, x\right\}=0.$$

We may write this condition in the form

$$\Sigma\, x^3\, \rho_x\, \delta\, x=3\, d^2\, \Sigma\, x\, \rho_x\, \delta\, x=3\, d^2\, a\, m,$$

which results in the relation

$$a_2=\sqrt{3}\cdot d,$$

where $2\,d$ is the distance of the two needles apart.

We thus come to the conclusion, where we take into consideration the nature of the magnetic distribution, that a more satisfactory spacing of the needles is obtained by arranging that the $p_2$ points subtend 60° at the card centre, rather than that the centres of gravity of the distribution subtend this angle.

The location of the $p_2$ points in typical needles, as used in compass construction, becomes therefore a matter of some little interest. Experimental means to this end are described later.

If instead of considering the effect of one pole only, $m'$, of a corrector magnet, we take both poles into the calculation, or if we take a number of magnetic elements to constitute a complete corrector magnet, we arrive at very similar results.

* Here $m$ is the quantity of magnetic matter in the half needle; $a$ the half polar length; $2\,a\,m$ the magnetic moment.

## SECTION II.

### COMPENSATION FOR SHIP'S MAGNETISM BY THE INTRODUCTION OF AUXILIARY MAGNETIC FIELDS.

In applying correctors to a compass for the elimination of the errors due to ship's magnetism, secondary errors are introduced by the correctors.

The object of this section, is, first, to investigate the magnitude of these secondary errors, and, secondly, to obtain a working notion of the magnetic forces due to the distribution of iron in several typical vessels.

This subject is intimately bound up with the analytical theory of the deviation of the compass, and in the form in which this Section was first written I had dealt with this theory in considerable detail. In view of the restricted space available in the *Journal*, however, I have curtailed this Section materially and must refer readers to the Admiralty Manual on the Deviation of the Compass, a most valuable book dealing exhaustively with the theory and practice of compass compensation.*

The Manual dates back to 1842, but was edited, enlarged, and in part rewritten in 1862 by Archibald Smith and F. J. Evans. New editions appeared in 1863, 1869, 1874, 1882, 1893, 1901, and 1912. It has been translated into Russian, French, German, and Portuguese, and may safely be regarded as a standard work on the subject.

In Appendix I, the theory of deviation is based on Poisson's fundamental equations, published in 1824, Vol. 5, Mémoires de l'Institut, p. 533, and is developed in an elegant manner.

The mathematics is not difficult, and may be grasped readily by many who make no pretensions to being gifted mathematicians. This being so, one cannot help feeling it is a mistake to emphasize and reiterate in the various prefaces that the analytical portions of the Manual are only intended for expert mathematicians. I know definitely of cases where readers have deliberately shunned the algebraical portions of the Manual for no other reason than the warnings contained in the prefaces.

It is true that the mathematical theory is translated into popular language in certain sections of the Manual,

* See also Maxwell's "Electricity and Magnetism," Vol. 2, Edition 2, p. 70; and the Obituary Notice by Lord Kelvin of Archibald Smith, *Transactions of the Royal Society*, 1874.

and the beautiful "nine-rod" theory employed to illustrate the phenomena in an exceedingly attractive manner; nevertheless, to the student who has fought shy of the algebraical work, there is ever a feeling that the rule-of-thumb methods he employs are based to some extent on occultism.

In the present communication we shall content ourselves with an abridged and, consequently, simplified study of this fascinating theory.

The most important equation is that defining the deviation of the compass produced by ship's magnetism, but when the equation is stripped of all its mysticism it just defines the position of the needle in which the algebraic sum of the turning moments of all forces tending to deflect it is zero. This is obviously the position of equilibrium, and the angle the needle makes in this position with the magnetic meridian is the deviation.

If $\zeta$ be the position of the ship's head measured easterly from the N-pole of the magnetic meridian;
$\hat{c}$ be the position of the needle when in equilibrium, measured easterly, as above;
$F_f$ be the magnetic force at the compass station, along the fore-and-aft line, due solely to the ship's magnetism, the positive direction being towards the ship's head;
$F_t$ be the magnetic force at the compass station, in the thwartship direction, due solely to the ship's magnetism, towards starboard being reckoned positive (the ship is supposed to be upright);

then, obviously, the position of equilibrium is defined by the equation

$$F_f \sin(\zeta-\hat{c}) + F_t \cos(\zeta-\hat{c}) - H \sin \hat{c} = 0 \quad . \quad (11)$$

Alternatively, we may resolve $F_f$ and $F_t$ into components along the meridian, and at right angles thereto, and we can write the ship's magnetic force acting from South to North as

$$F_f \cos \zeta - F_t \sin \zeta \quad . \quad . \quad . \quad . \quad (12)$$

and acting from West to East as

$$F_f \sin \zeta + F_t \cos \zeta \quad . \quad . \quad . \quad . \quad (13)$$

All of these expressions are intelligible to anyone familiar with the everyday meaning of trigonometrical symbolism.

Equation (11) defines the direction $\hat{c}$, of the resultant magnetic force.

Expression (12) represents the modification of the directive force in the meridian, due to the ship's magnetism.

Expression (13) represents the East-Westerly force due to the ship's magnetism, or the force producing deviation.

We require then to study in some detail the constituents of the fore-and-aft force $F_f$, and the thwartship force $F_t$ which arise from the ship's magnetism, and having fully defined them we may insert the definitions in (11), (12), and (13), and thus arrive at a complete analysis of the sources and amount of the deviation, the conditions of its annulment, and the behaviour of the various correctors applied for the purpose.

In order that we may be quite clear as to the assumed direction in which the earth's magnetism is operating in space, I would say that I consider the lines of force as emerging from the South polar region and entering the North polar region. Thus our usual convention is reversed when we consider the earth as a magnet. It appears to me, however, that we electrical engineers must adopt this convention, in order to harmonize with our conventions regarding the direction of magnetic force around a conductor carrying a current.

If we look along the axis of a helix in which current is circulating in a clockwise direction, the magnetic force along the axis of the helix is represented by the arrow pointing away from us. The arrow-point seeks the pole of the earth's Northern hemisphere.

In speaking of the N end of a needle, we mean the N-seeking end, or the end which seeks the magnetic pole in the Northern hemisphere—it seeks, of course, the South end of another bar magnet—and we consider the lines of force as emerging from the N-seeking end, and entering the S-seeking end.

To overcome the confusion involved by having to consider the earth as a "reversed" magnet, compass adjusters think only of red magnetism and blue magnetism. The magnetism of the Northern terrestrial region is of the blue variety, that of the Southern terrestrial region of the red variety. The N-seeking pole of the compass needle is painted red, the S-seeking blue. This suggestion was originally made by Sir George Airy.

Let us first consider that constituent of the ship's magnetism which may be regarded as permanent for the time being. By "permanent" we mean unvarying as regards strength and direction in relation to the ship's axes, no matter what direction the ship may be heading, and no matter at what part of the earth the ship may be, assuming she could be transported bodily and instantaneously from place to place.

The field at the compass station, due to this permanent magnetism, will have some definite strength and some definite direction, and we may consider its three components as follows:—

P directed to the ship's head along the fore and aft line.
Q directed to starboard along a thwartship axis.
R directed to keel, vertically.

P is thus one of the constituents of $F_f$, while Q is a constituent of $F_t$. As we are only considering the case of the upright ship, R will not enter into the calculation.

The other constituents of ship's magnetism are induced effects, i.e. due to the magnetic state induced in the soft iron by the earth's field.

We again require to consider these induced effects in the fore-and-aft, the thwartship, and the vertical directions, and we must therefore consider the components along these axes of the earth's inducing force; the positive direction along the axes will be as above defined.

If the ship's head be at $\zeta$, the earth's force in the fore-and-aft direction is H cos $\zeta$, in the thwartship direction is $-$H sin $\zeta$, and in the vertical direction is V, being independent of $\zeta$.

Now the earth's force in the fore-and-aft direction induces magnetism in the ship's iron which may give rise to magnetic forces at the compass station, as follows :—

| | |
|---|---|
| (1) in the fore-and-aft direction<br>(2) in the thwartship ,,<br>(3) in the vertical ,, | All assumed proportional to the inducing force, H cos $\zeta$. |

Similarly, the earth's force in the thwartship direction may induce magnetism producing at the compass station the following forces :—

| | |
|---|---|
| (4) in the fore-and-aft direction<br>(5) in the thwartship ,,<br>(6) in the vertical ,, | All assumed proportional to the inducing force, $-$H sin $\zeta$. |

While the earth's vertical component may give rise to components of force :—

| | |
|---|---|
| (7) in the fore-and-aft direction<br>(8) in the thwartship ,,<br>(9) in the vertical ,, | Assumed proportional to V. |

In the "nine-rod" theory already referred to, each rod corresponds to one of these nine induced effects.

We have only to imagine a soft iron rod introduced into a uniform field, the axis of the rod being parallel to the direction of the field, and think of the way the lines of force curve round and crowd into the ends, to appreciate how vertical and transverse components of magnetic force arise in the free space near the ends.

We see that the fore-and-aft force $F_f$ is made up of the following constituents : P (the component due to permanent magnetism, and (1), (4), and (7)—components due to induced magnetism.

Further, that the thwartship force $F_t$ comprises Q (due to permanent magnetism), and (2), (5), and (8)—induced effects.

An investigation of the induced effects (1) to (9) shows us that (2), (4), and (8) disappear when the distribution of the iron in the ship is symmetrical about the fore-and-aft vertical plane through the compass. Since the compass is nearly always on the fore-and-aft centre line of the ship, the arrangement of the iron is nearly always symmetrical to port and starboard of the compass, and, except in quite unusual circumstances, components (2), (4), and (8) may be disregarded.

The effect (7) would disappear if the distribution of iron were symmetrical about the thwartship vertical plane passing through the compass. Such a distribution does not occur, however, and this component is one of great importance.

It will be remembered that (7) is the horizontal force in the fore-and-aft direction due to magnetism induced by the earth's vertical force V.

We can picture how such horizontal force arises by looking at Fig. 13 (*a*).

Imagine a vertical stanchion or a bulkhead magnetized inductively under the influence of the vertical force V. The horizontal arrow indicates the fore-and-aft direction. The upper end of the stanchion becomes a S-seeking pole, the lower end a N-seeking pole ; then, clearly, the horizontal fore-and-aft force will be increased at A and decreased at B.

In Fig. 13 (*b*) we have an arrangement of iron in which this effect of horizontal force arising from vertically induced magnetism is emphasized.

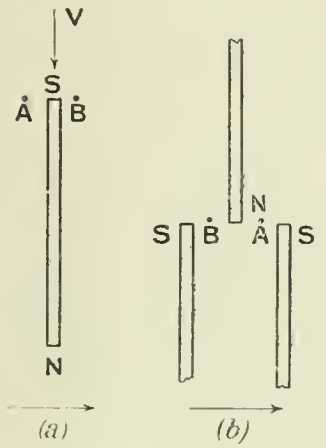
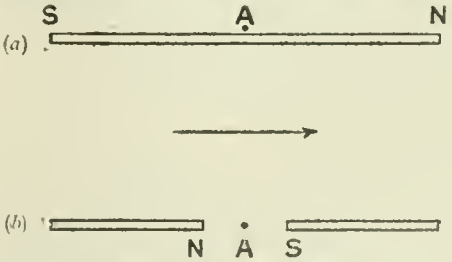



Fig. 13.

If $c$ be the numerical value of the horizontal force at any point due to vertically induced magnetism when the magnetizing force is unity, V $c$ is the horizontal force at the same point when the vertical force is V. Referring to the compass station on a ship, $c$ is positive when the fore-and-aft force V $c$ is directed towards the ship's head. This depends upon whether the greater portion of the ship is in front of or behind the compass,




Figs. 14 (*a*) and 14 (*b*).

upon the relative position of funnels, steel masts, and the distribution of iron generally, and also upon whether the ship is in the Northern or Southern hemisphere. As she crosses the magnetic equator, the sign of V changes, consequently also that of V $c$.

Coming now to induced effects (1) and (5), we observe that these may be due to symmetrically or unsymmetrically placed iron. Consider the ship's head on N ; the earth's horizontal field will magnetize the members of the ship in a fore-and-aft direction, creating a N-pole at the bow and a S-pole at the stern. This magnetization will produce horizontal force at the compass station in the opposite direction to that of the earth.

If in Fig. 14 (*a*) we consider a plate seen edgewise as representing the horizontally lying members susceptible to the earth's horizontal force, we may consider the lines of force as crowding into the ends and leaving a deficit at a point near the centre, say A. Or we may consider poles created by induction, as at N and S, giving rise to a force at A opposed to that of the inducing field. It is immaterial which convention we adopt.

If $a$ be the numerical value of the force at A due to the poles N–S, when the inducing force is unity, H $a$ will be the force at A when the inducing force is H. In the case indicated in Fig. 14 (*a*), the numeric $a$ is negative. Fig. 14 (*b*) indicates a case where the plate is discontinuous; in this instance the direction of the force at A is the same as that of the inducing field, i.e. $a$ will be positive.

If the ship's head be at $\zeta$, the value of the fore-and-aft component due to induced magnetism is H $a \cos \zeta$.

Next, suppose the ship's head is at W, the horizontal iron becomes magnetized in the thwartship direction under the action of the earth's horizontal force; this force acts in the positive direction, i.e. from the compass station to starboard, hence the component of the induced magnetism, directed to starboard, may be written as H $c$. When the ship's head is at $\zeta$ the inducing force thwartships is $-$H $\sin \zeta$, hence the thwartship component (5) is $-$H $e \sin \zeta$.

We can, therefore, write :—

$$\left.\begin{aligned} F_f &= P + V\,c + H\,a \cos \zeta \\ F_t &= Q \qquad - H\,e \sin \zeta \end{aligned}\right\}$$

If we insert these values in (11) we arrive at the expression for the deviation as found in the Manual on the assumption that the distribution of iron is symmetrical about the vertical fore-and-aft plane through the compass.

If we insert the values in (12) we obtain the alteration of the directive force due to the ship's magnetism.

If we insert them in (13), we have the East–Westerly component, due to ship's magnetism.

The latter may be written in the form :—

$$[P + V\,c] \sin \zeta + Q \cos \zeta + H \left[\frac{a - e}{2}\right] \sin 2\zeta \quad . \quad (14)$$

The first two terms represent what is called semicircular disturbing forces, because they create positive deviation in the one semicircle and negative deviation in the remaining semicircle. The third term is known as a quadrantal disturbing force, since its direction is alternately positive and negative in the successive quadrants.

Correctors are applied to eliminate deviation as follows :—

Permanent magnets to compensate for P and Q;
The Flinders' bar to compensate for V $c$; and
The quadrantal globes to eliminate the $a$ and $e$ effects.

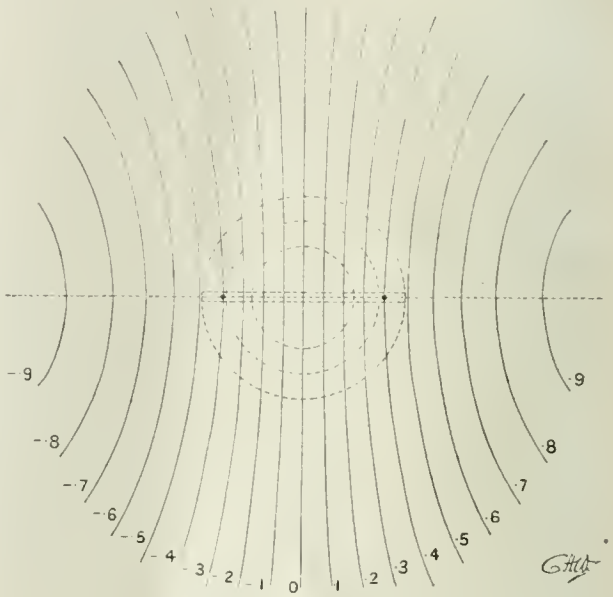
These correctors modify the values of P, Q, $c$, $a$, and $e$ (P and Q are forces, $c$, $a$, and $e$ are numerics only, but H $a$, H $c$, and V $c$ are forces); let the modified values be P″, Q″, $c''$, $a''$, and $e''$. Then in order that (14) may vanish we must have

$$\left.\begin{aligned} P'' &= 0 \\ Q'' &= 0 \\ c'' &= 0 \end{aligned}\right\} \quad a'' = e'' \qquad \ldots \quad (15)$$

and we have to inquire how far these conditions are met in practice.

The permanent magnets are placed in the fore-and-aft and thwartship directions, being disposed in suitable receptacles provided in the binnacle at planes considerably below that of the card, say 20 inches below.

The lines where the surfaces of equal potential due to a horizontal corrector magnet 8 inches long cut a horizontal plane 50 cm. above or below the magnet




*Intersection of equi-potential surfaces by plane 50 cms. above magnet and parallel with axis.*

FIG. 15.

have been kindly calculated and drawn for me by Mr. C. H. Wright, and are shown in Figs. 15 and 16.

They are not absolutely straight and uniformly spaced, and consequently the compensation is not theoretically perfect.

(The dotted circles in Figs. 15 and 16 show the areas swept out by 4-inch, 6-inch, and 8-inch compass needles respectively in the horizontal plane 50 cm. above or below the corrector magnet.)

In the ordinary merchant service or standard Naval compass, the corrector magnets are sufficiently far away, and the compass needles sufficiently short, however, for any secondary errors arising from this source to be safely disregarded.

In special cases, as, for example, in some submarine compasses, it is necessary to inquire into the magnitude of the sextantal deviation which arises.

If the magnet be situated in a plane $h$ cm. above

or below that of the card, the values of the coefficients $A_1$ and $A_3$* in (8) require modification, as follows :—

$$A_1 = \frac{a\,b}{d^3}\left[1 - \frac{3\,a^2}{2\,d^2} + \frac{15\,a^2\,b^2}{8\quad d^4}\right],$$

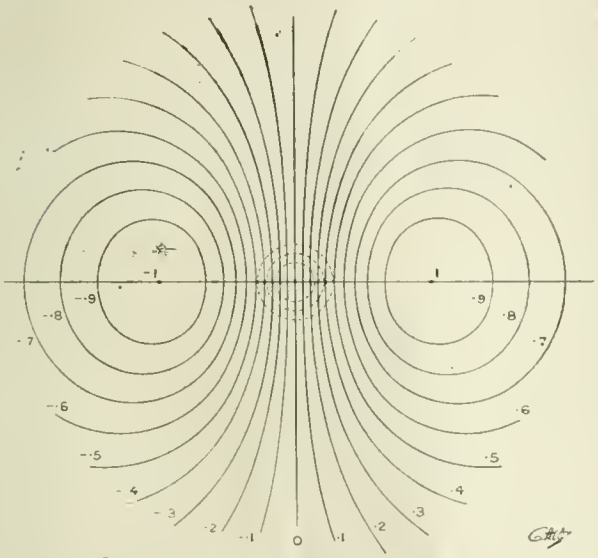
$$A_3 = \frac{a\,b}{d^3}\left[\frac{15\,a^2\,b^2}{8\quad d^4}\right],$$

where $d^2 = b^2 + h^2$.

These coefficients inserted in (7) give us the torque on the single needle due to a single pole $m'$ situated at a distance $b$ from the axis, other factors being as before.

It will be observed that if we make $h = 0$ we obtain the values of $A_1$ and $A_3$ given in (8) as far as the second power of the ratio $a/b$.

As a rule the magnets are placed in two groups, one on either side of the vertical axis, but the corresponding expressions for $A_1$ and $A_3$ with a single or compound




*Intersection of equi-potential surfaces by plane 50 cms. above magnet and parallel with axis.*

FIG. 16.

needle may be derived for any special case on the lines already indicated.

The Flinders' bar is in general very much nearer to the compass card than the corrector magnets. The upper end is approximately in the plane of the card and behaves as a magnetic pole under the action of the earth's vertical force.

In this case the values of the coefficients in (8) are applicable, and, owing to the proximity of the card, the ratio of $a/b$ may be as great as 1/3.

Inserting $a/b = 1/3$ in (8), we find that the sextantal term for a single needle amounts to 20 per cent of the semicircular effect.

In the case of two needles, we have

$$A_1 = \frac{3\,a}{b^2}\left[1 + \frac{3\,a^2}{8\,b^2}\right]\cos a + \text{etc.},$$

$$A_3 = \frac{2\,a}{b^2}\left[\frac{15\,a^2}{8\,b^2}\right]\cos 3\,a + \text{etc.},$$

so that if the needles be placed with their effective poles at 30°, i.e. $2a = 30°$, the sextantal amounts to 14½ per cent of the semicircular term.

Again, if the needles be placed so that $2a = 90°$, the sextantal bears the same ratio to the semicircular effect as in the single-needle case.

As the amount of the correction effected by the Flinders' bar in high magnetic latitudes in either hemisphere is often considerable, the sextantal term in the above case would represent a serious deviation.

The equipotential lines are shown in Fig. 3 ; they are circles drawn from the axis of the bar as centre.

It may be well to point out that when we are considering the component of force in a plane, due to a field of which the component normal to the plane varies from point to point, we cannot advantageously draw lines of force in that plane. The force undoubtedly has a definite direction along the plane at each point of the plane, and it would be quite feasible to draw so-called lines of force, but to do so is confusing, as it upsets our conventions regarding lines of force.

Generally speaking, we not only regard the line of force as indicating the direction of force, but we regard the "crowdedness" of the lines as indicating

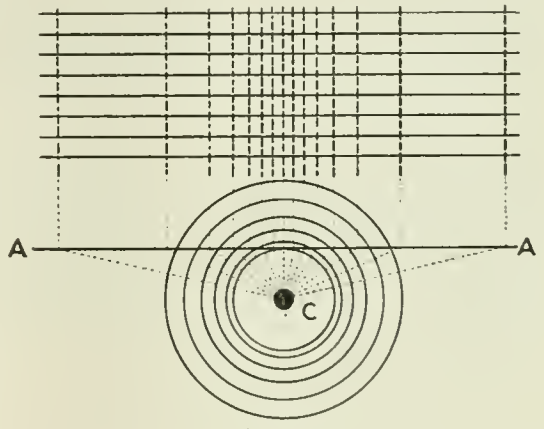



FIG. 17.

to a certain extent the magnitude of force. Further, we conceive of a line of force as a closed curve. If, however, we draw lines of force in a plane, cutting a field of force of the character described, we find that such lines of force terminate at a point or region where the field becomes normal to the plane.

Again, the crowdedness of the lines of force is no indication of the magnitude of force. As this is an important matter to recognize, I will give an illustration (see Fig. 17).

Let C be a straight conductor carrying an electric current. The field of force is represented by concentric circles, the equipotential lines by radial lines. A A is a plane cutting the field of force. Now, at every point in the plane, there will be force along the direction A A; thus the lines of force are straight parallel lines, and the crowdedness is uniform everywhere. But the force is by no means constant. At infinity in either direction the force is zero, while the maximum value is at points vertically above the conductor.

* See *Philosophical Transactions of the Royal Society*, 1861, p. 171.

If, however, we regard the lines of equal potential in the plane A A, we see that they are most crowded in the centre above the conductor, while they become less and less crowded as we proceed in either direction away from the centre. At infinity, the distance between two successive lines must be regarded as infinite.

The equipotential lines thus indicate at every point the direction which is at right angles to the force, while by their crowdedness they indicate the magnitude of the force. This is necessarily so from the definition of potential, viz. a function such that its rate of change in any direction is the force in that direction.

Again, referring to Fig. 16, the equipotential lines are the lines of intersection of a plane with certain surfaces of revolution, or envelopes enclosing the poles of the magnet situated below the plane. The lines are thus closed curves and enclose certain points or loci representing the points where two of the envelopes just touch the plane without cutting it. The successive equipotential lines are thus closed curves around these loci, of diminishing proportions, the loci representing curves of infinitesimal dimensions.

The force at the loci is obviously normal to the plane, i.e. there is no force there in the plane. Had we drawn the lines of direction of force in the plane, we should have lines starting from one locus and ending at the other, cutting the lines of equal potential orthogonally. We should then have lines of force most crowded where the actual force in the plane is zero, and other apparent anomalies leading to a confusion of ideas, which it is best to avoid.

We now come to the consideration of the quadrantal correctors.

It will be observed that while it would be possible to eliminate quadrantal deviation by making $a''=e''=0$, it is sufficient if we merely make $a''=e''$ [see (15)].

If $a$ and $e$ be the coefficients for the ship alone, and if $a'$ and $e'$ be the coefficients for the quadrantal correctors alone, then

$$a''=a+a'(1+a),$$

and

$$e''=e+e'(1+e).$$

Hence we require the relation

$$a+a'(1+a)=e+e'(1+e) \quad . \quad . \quad . \quad (16)$$

As a general rule in merchant ships, $a$ is a negative quantity less than unity, $e$ is a negative quantity less than unity but several times greater than $a$ (because the thwartship induced poles are nearer to the compass than those induced on the fore-and-aft axis). Thus $(a-e)$ is a positive quantity less than unity.

Now, the values of $a'$ and $e'$ for a pair of globes are readily calculable.

If a sphere of iron be introduced into a uniform field of strength H, the force at the point $k$, $\theta$, along the radial line O P is very approximately

$$\frac{2\,H\,r^3\cos\theta}{k^3} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

radially outward, and

$$\frac{H\,r^3\sin\theta}{k^3} \quad . \quad . \quad . \quad . \quad . \quad (18)$$

at right angles to the radius in a direction tending to increase $\theta$ (compare J. J. Thomson, "Mathematical Theory of Electricity," p. 258)—see Fig. 18.

If, now, we consider two spheres arranged E and W, the magnitude of the force at the centre of the card will be $-2\,H\,r^3/k^3$, $k$ being the distance of the centre of each sphere from the axis of the compass; the direction of force is in opposition to the earth's field.

Hence
$$H\,a'=-2\,H\,r^3/k^3$$
or
$$a'=-2\,r^3/k^3\ *$$

Similarly, if the globes are arranged N and S we have

$$H\,e'=4\,H\,r^3/k^3$$
or
$$e'=4\,r^3/k^3.$$

Inserting these values for $a'$ and $e'$ in (16) we obtain

$$\left.\begin{aligned} k&=r\sqrt[3]{\left[\frac{2\,(3+a+2\,e)}{(a-e)}\right]}\\ \text{and}\quad a''=e''&=\frac{2\,a+3\,a\,e+e}{3+a+2\,e}\end{aligned}\right\} \quad . \quad . \quad . \quad (19)$$

From which we learn that for given values of $a$ and $e$, there is a definite distance, $k$, measured from the

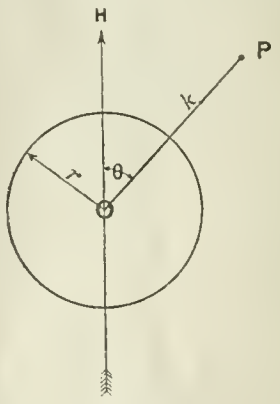



Fig. 18.

centre of the compass, at which we must set our globes (of radius $r$) in order that the East–Westerly component at the compass centre may be neutralized.

The question now arises: If the globes be so arranged that the deviation of the *earth's field* is zero, will the compass card point true magnetic North?

The answer is: Not necessarily. It will only do so, provided the needles be sufficiently short, and provided the magnetic moment be sufficiently small.

Suppose we take a binnacle and arrange a pair of $8\frac{1}{2}$-in. globes, each 12 inches from the axis in the N-E and S-W quadrantal line; the direction of the earth's field at the centre of the compass will be N 7·3° E, i.e. the globes cause a deviation at the centre of 7·3° E. In the following table the observed deviation of a number of cards is given, under the precise conditions mentioned.†

* See also *Philosophical Transactions*, 1865, p. 319.

† In all cases where the figures depend upon the value of H, it is to be understood they apply for an H-value corresponding to that at Glasgow.

| | Reading | "Inductive" Deviation |
|---|---|---|
| Kelvin 10-in. card .. .. | 7·3° | — |
| Naval standard compass .. | 10·0° | 2·7° |
| Naval torpedo boat compass.. | 10·0° | 2·7° |
| Ritchie 7½-in. card .. .. | 11·65° | 4·35° |
| Ritchie 9-in. card .. .. | 18·9° | 11·6° |
| Common steering compass .. | 13·2° | 5·9° |

The Kelvin card takes up practically the direction of the resultant field existing when no card is in position, but in all the other instances the needles are deflected towards the globes. This is due to their inductive action on the spheres; in other words, they induce magnetism in the spheres which, attracting the needles, causes what I have termed "inductive deviation." The objectionable nature of this deviation has already been pointed out.

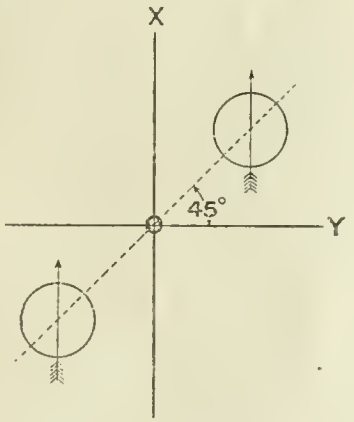



FIG. 19.

If a ship be adjusted, say, on the Clyde so as to exhibit no quadrantal deviation, part of the deviating effect of the ship's quadrantal iron is compensated by the inductive effect.

The directive force is proportional to H, but the deviating force due to inductive action is independent of H; hence, if the ship sails to Singapore, where H is about 2·3 times the Clyde value, the error on a quadrantal course will be approximately 0·57 $d$,* where $d$ is the "inductive" deviation caused by the globes when the directive force corresponds to the Clyde value of H.

Thus if $d$=4·3° as in the case of the Ritchie 7½-in. compass with 8½-in. globes at 12-in. centres, and the ship be adjusted to show no deviation on the Clyde, a deviation of 2·4° would appear on quadrantal courses in the neighbourhood of Singapore.

* If a compass be adjusted, where the horizontal force is H, to show no deviation, and if the inductive effect represents $d°$, the actual deviation on a quadrantal course at another place where the horizontal force is $n$H, is $(n-1)\,d/n$.

It is to be noted that when the quadrantal effect of a ship has once been correctly compensated for a sufficiently short needle compass of sufficiently small magnetic moment, the quadrantal compensation is complete for all time, for all courses, and for all parts

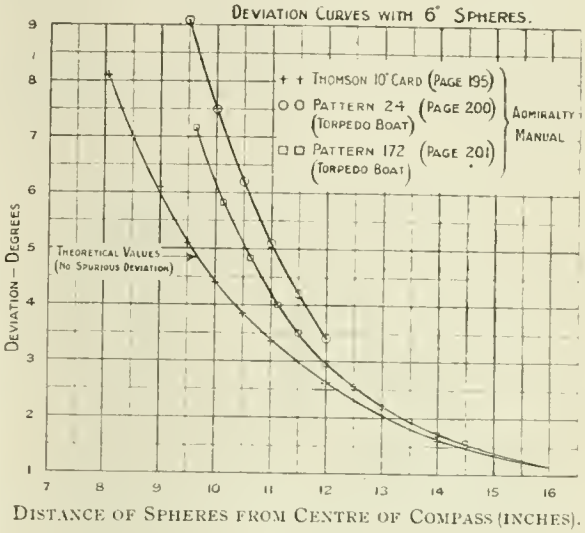

DEVIATION CURVES WITH 6" SPHERES.
+ + THOMSON 10" CARD (PAGE 195)
O O PATTERN 24 (TORPEDO BOAT) (PAGE 200)
□ □ PATTERN 172 (TORPEDO BOAT) (PAGE 201)
ADMIRALTY MANUAL
THEORETICAL VALUES (NO SPURIOUS DEVIATION)
DEVIATION – DEGREES
DISTANCE OF SPHERES FROM CENTRE OF COMPASS (INCHES).

FIG. 20.

of the earth, provided no redistribution of the ship's iron be made.

It will be understood that, in the ideal arrangement, we should neutralize the East–Westerly component in the *space* where the compass bowl is to be placed, so that any "ideal" compass introduced into that space

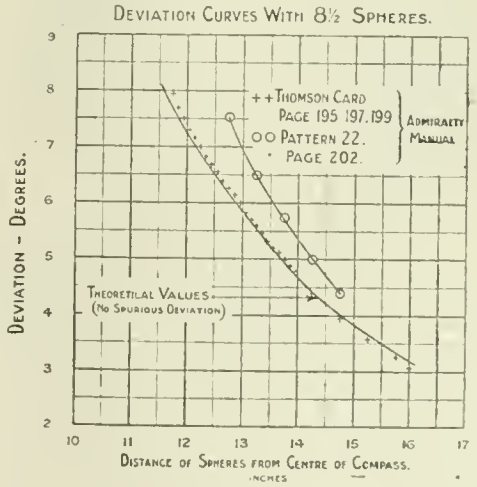

DEVIATION CURVES WITH 8½ SPHERES.
++THOMSON CARD PAGE 195 197.199
OO PATTERN 22. PAGE 202.
ADMIRALTY MANUAL
THEORETICAL VALUES (NO SPURIOUS DEVIATION)
DEVIATION – DEGREES.
DISTANCE OF SPHERES FROM CENTRE OF COMPASS.

FIG. 21.

will point "true." In actual practice, however, when dealing with a card of large magnetic moment, we must leave a proportion of the East–Westerly component unbalanced so that the inductive drag on the needles may be compensated by the residual E–W component.

Thus, if the card be replaced by another of different magnetic moment, the substituted card will no longer point "true."

In the Admiralty Manual, tables are given showing the actual value experimentally determined of the deviation caused by different sizes of globes at different distances from the compass centre when different types of compass bowls are employed, the spheres being disposed on a quadrantal axis.

Now, the theoretical deviation of the earth's field is readily calculated. We are thus enabled to determine from the data in the Manual the order of magnitude

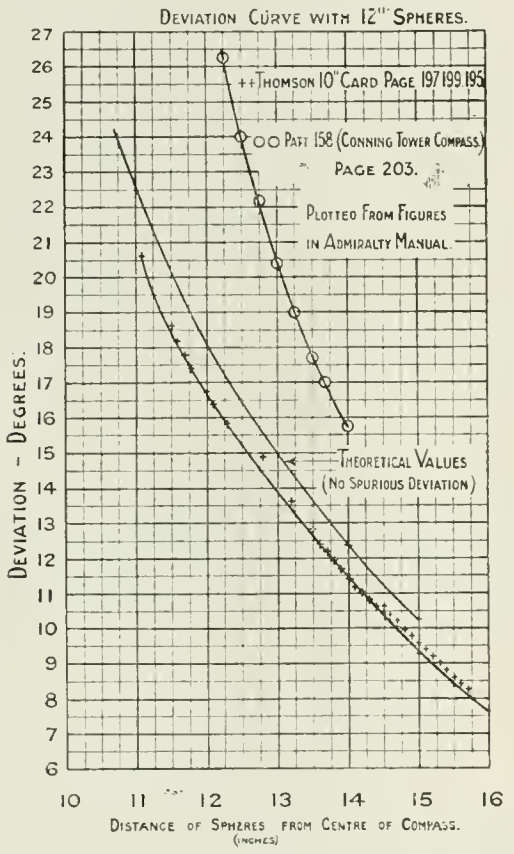

Deviation Curve with 12" Spheres.
++Thomson 10" Card Page 197 199 195
OO Patt 158 (Conning Tower Compass) Page 203.
Plotted From Figures in Admiralty Manual.
Theoretical Values (No Spurious Deviation)
Deviation - Degrees.
Distance of Spheres from Centre of Compass. (inches)

Fig. 22.

of the "inductive" deviation of the various Admiralty patterns.

The deviation of the earth's field for a pair of globes may be arrived at as follows:—

Referring to Fig. 19 and to expressions (17) and (18), we see that the force at the centre O due to the globes along O X is $H r^3/k^3$, and along O Y is $3 H r^3/k^3$.

The globes are sufficiently far apart to ensure that the magnetism of the one does not produce effects in the other. The directive force (or whole force along O X) is $H [1 + r^3/k^3]$, and the deviating force is $3 H r^3/k^3$, as above. Hence the tangent of the angle of deviation is

$$\frac{3 r^3}{r^3 + k^3}.$$

In Figs. 20, 21, and 22 the deviation of the earth's field calculated in this way, together with the observed deviation of the different Admiralty patterns, are shown on the curves:—

I. With 6-in. globes (see Fig. 20, showing comparison of Thomson 10-in. card with Admiralty patterns of liquid compasses 24 and 172 for torpedo boats).

II. With $8\frac{1}{2}$-in. globes (see Fig. 21, showing comparison of Thomson 10-in. card with Admiralty pattern 22, viz. the standard liquid compass).

III. With 12-in. globes (see Fig. 22, showing comparison of Thomson 10-in. card with Admiralty pattern 158 liquid compass, used in lower conning station of battleships).

These curves are the necessary deductions from a comparison of the carefully observed results published in the Manual on pages 197, 202, and 203, with the theoretical result indicated in the footnote on page 105 in the same publication.

It is interesting to observe that the deviations of the Thomson 10-in. card, in the case of the 12-in. globes, lie below the theoretical values.

I have also found this to be the case when testing the Thomson card with 10-in. or 12-in. globes, and I attribute it to the thinness of wall of the hollow globes. Lord Kelvin gave the rule that, in order for hollow globes to behave as solid ones, the wall thickness should be not less than one-tenth of the diameter. In the large globes this is not so.

If this be the explanation, we must consider the "inductive" deviation in the case of the liquid compasses as even greater than shown by the curves.

Attention is particularly drawn to the instance of the conning-tower pattern of compass, where with 12-in. globes at a distance of 12·25 inches from the centre, the "inductive" deviation amounts to 9° or even more.

In addition to the inductive error, we have the length-of-needle effect due to the non-uniformity of the field in the region between the spheres.

It will be unnecessary to emphasize the fact further, that in a non-uniform field a long needle with its poles swinging in one region of the field will behave differently from a short needle, with its poles near to the centre. The effects are known as octantal deviations, and their magnitude is investigated in the next section.

The lines of equal potential in the space surrounding the globes are very instructive. They have been calculated and drawn for me, very kindly, by Mrs. and Mr. F. A. King.

Fig. 2 represents the family of equipotential lines in the plane of the paper due to two doublets, directed N–S, but situated on the E–W axis.

Fig. 23 represents the family when the doublets, always pointing in the same direction, are situated on the S-W—N-E axis.

Fig. 24 shows the family when the doublets are on the N–S axis.

It is interesting to compare the deviation indicated by the slope of the equipotential lines in the centre of Fig. 23 with the calculated values of deviation; in fact, a general study of all the various systems of equipotential lines involved by the problem of the

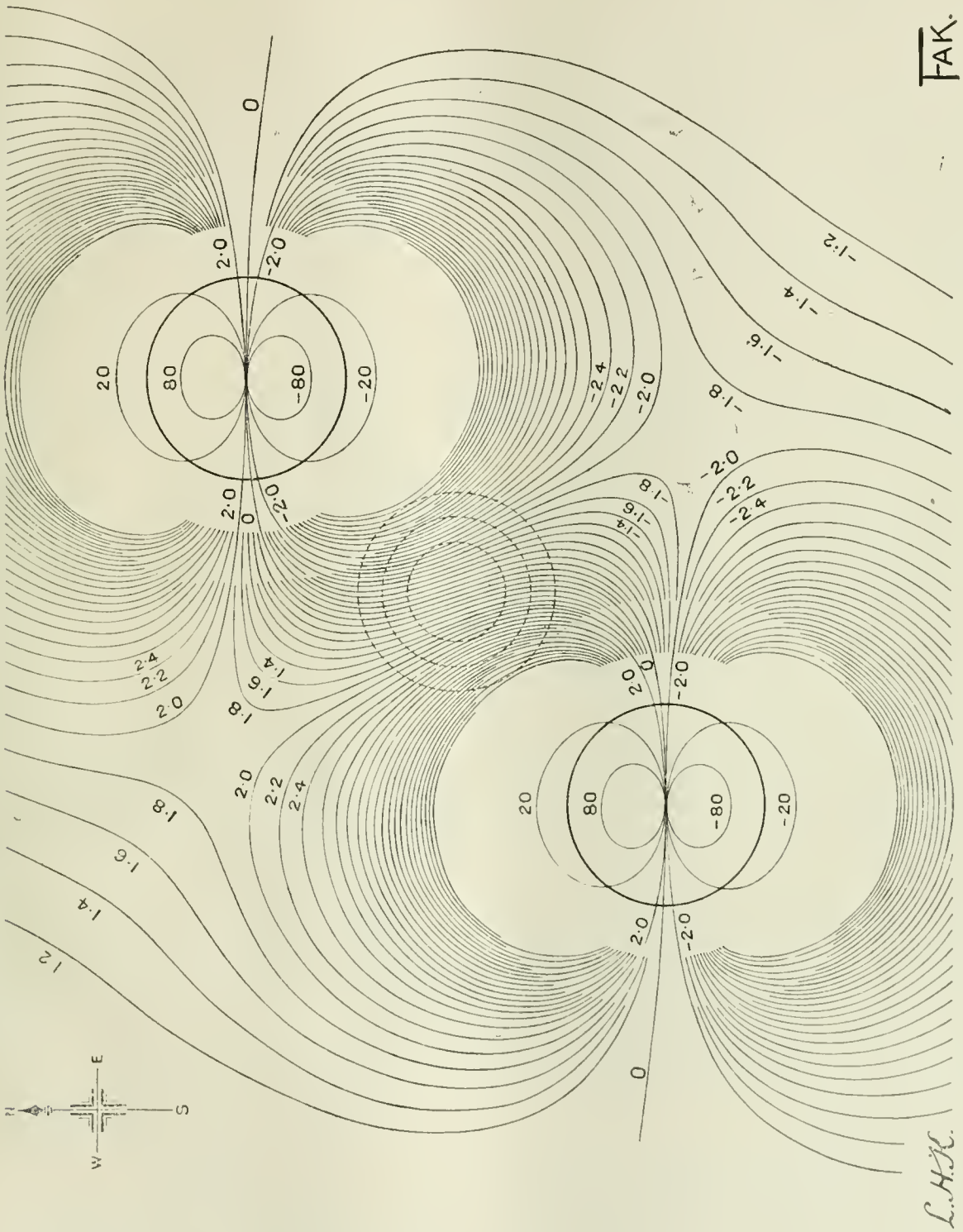



FIG. 23.—Intersection of equipotential surfaces with plane of compass card. Spheres SW—NE.

compass is well worth while for the student. Space, however, does not permit of a further digression, in this paper, into this extremely interesting side-issue.

square centimetre (C.G.S. system) or in terms of the earth's horizontal field, say, at Glasgow (=0·16 C.G.S. units).

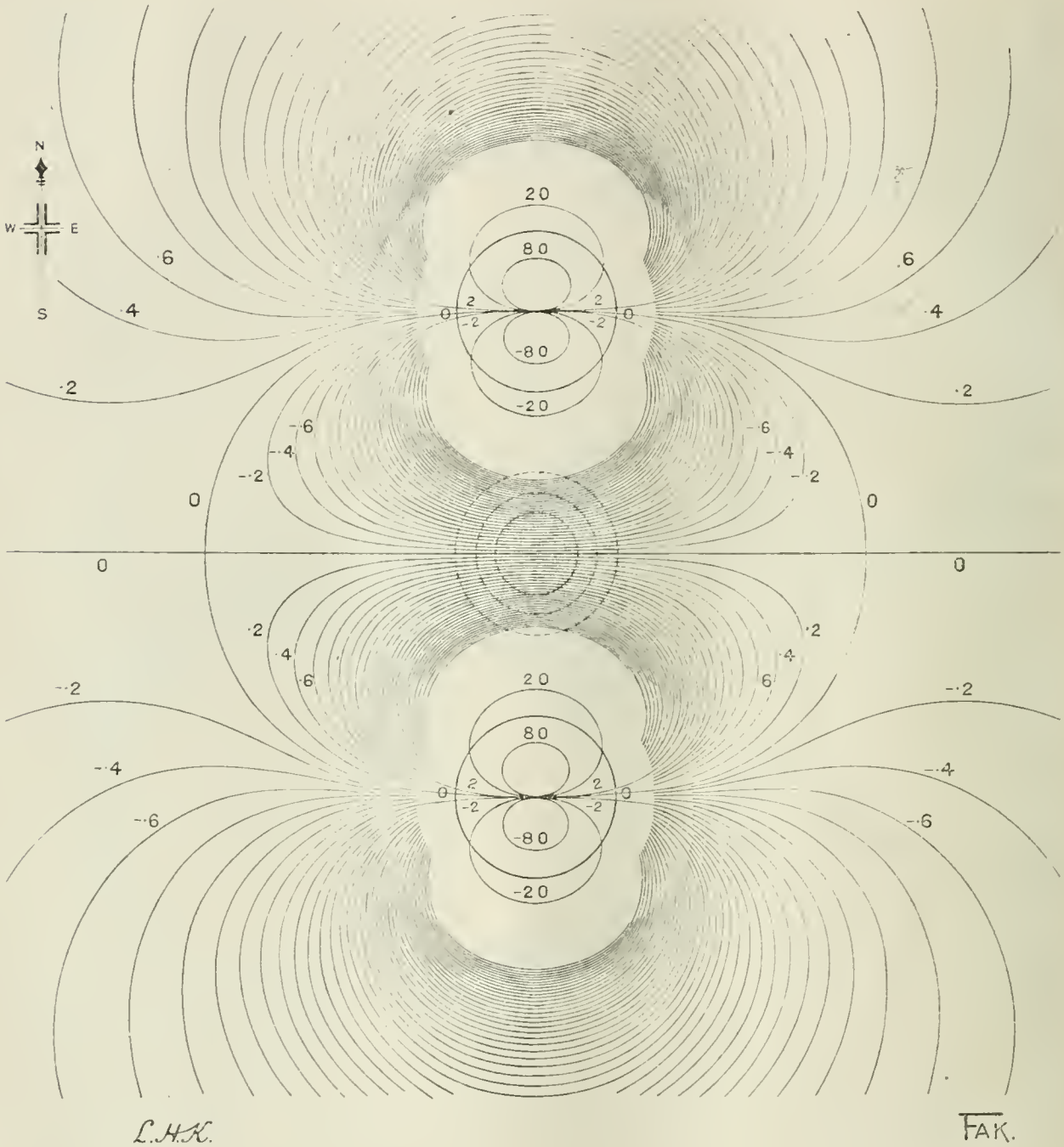



FIG. 24.—Intersection of equipotential surfaces with plane of compass card. Spheres N—S.

We will now take the case of a few well-known liners and obtain a working notion of the magnitude of the magnetic forces due to the ship's iron, which operates at the position of the standard compass. We may express these magnetic forces in terms of lines per

Let us take the cases of s.s. "Aquitania," s.s. "Titanic," s.s. "Lusitania," and s.s. "Mauretania."

The position of the correctors for complete compensation being known, the magnetic forces operating are readily deducible; it is only necessary to take

each corrector by itself, place it in the corresponding position in the binnacle, turn the binnacle in a suitable position, and note the deviation of the card. The magnetic force at the card is thus obtained, and hence that of the corresponding effect due to ship's magnetism.

For example, knowing the number and position of standard magnets placed thwartship to compensate for Q, we place the binnacle with its lubber line in the meridian, insert the magnets and observe the deflection. We may then turn the binnacle through 90° and repeat the operation with the magnets which are known to have been necessary to compensate for P, and so on.

The following table has been derived in this way from records of the compass adjustment of the ships in question.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Ship | Fore and Aft Permanent Magnetism | Maximum Deviation if Uncorrected | Thwartship Permanent Magnetism | Maximum Deviation if Uncorrected | E–W Field due to Induced Magnetism. Ship on Quadrantal Course | Error if Uncorrected | Fore and Aft Field due to Vertical Induced Magnetism | Maximum Error if Uncorrected |
| | P | | Q | | | | Vc. | |
| "Aquitania" .. .. | 0·053 | 21° | 0·020 | 8·25° | 0·017 | 7·0° | 0·035 | 14° |
| "Titanic" .. .. .. | 0·011 | 4·5° | 0·011 | 4·5° | 0·026 | 10·5° | 0·026 | 10·5° |
| "Olympic" .. .. .. | 0·018 | 7·2° | 0·027 | 11·0° | 0·02 | 8·0° | — | — |
| "Lusitania" .. .. | 0·034 | 13·75° | 0·0245 | 10·0° | 0·017 | 7·0° | 0·026 | 10·5° |
| "Mauretania" .. .. | 0·023 | 9·3° | 0·072 | 27·5° | 0·019 | 7·8° | 0·026 | 10·5° |

Columns 2 and 4 represent C.G.S. values of ship's permanent magnetism at compass station.
Columns 3 and 5 represent probable maximum deviations on Clyde, if uncorrected.
Column 6 represents C.G.S. value of induced magnetism, on Clyde, on quadrantal course—at compass station.
Column 7 represents probable maximum deviation, if uncorrected.
Columns 8 and 9 represent horizontal force in C.G.S. units at compass due to vertical magnetization, Clyde value; and Clyde value of deviation, if uncorrected.

There is another effect of ship's magnetism which requires compensation which I have not touched upon. It is called Heeling Error. When a ship heels, the distribution of iron in relation to the earth's forces, H and V, is completely changed and new deviations arise.

Thus when a ship rolls, there is a strong tendency for the compass to oscillate violently unless the "heeling error" is adequately corrected.

Reference is made to the Admiralty Manual for a detailed discussion of the cause and effect of heeling error.

## SECTION III.

### The Magnetic Field in the Region of the Quadrantal Correctors.

It has been mentioned that the magnetic field in the region between two spheres, such as quadrantal correctors, is by no means uniform, and that with long needles a length-of-needle error is liable to occur. In order to study this question, it is necessary to inquire into the magnetic field in the external space when a soft iron sphere becomes magnetized (inductively) by being placed in a field previously uniform, such, for example, as the earth's field.

We know that the magnetic effect at external points is the same as if a sphere of unit permeability were substituted for the soft iron globe and a magnetic doublet of moment $F r^3$ were placed at its centre, where F is the strength of the uniform field, $r$ the radius of the sphere, and the direction of the doublet is that of the original field. (Compare J. J. Thomson: "Mathematical Theory of Electricity," page 151.)

A soft iron sphere in the earth's field may therefore be conceived, as far as points external to the sphere are concerned, as a doublet directed along the line of dip. Such a doublet may be resolved into components by the ordinary rules applicable to the resolution of forces; hence it can be replaced by a vertical doublet of moment $V r^3$, and a horizontal doublet in the direction of the earth's horizontal force of moment $H r^3$.

So long as the horizontal equatorial plane of the globes is that of the card, the vertical doublets can produce only vertical force on the needles, and we may therefore confine our attention to the action of the horizontal doublets.

I have found this conception, viz. the substitution of a magnetic doublet for the sphere itself, subject to the restrictions named, a most useful one in dealing with the problem under consideration, and, at the expense of a slight digression, I propose to give an instance in illustration.

It was at one time common practice with the Admiralty to mount compasses in pairs, in what were

known as double binnacles, apparently with the idea that the one compass would form a check upon the other. Captain Johnson, R.N., F.R.S., Superintendent of the Compass Department, Admiralty, observed that the compasses were so near that the one seriously influenced the other, and on his calling attention to what he considered to be a danger involved by such practice, the double-binnacle pattern was discarded.

Captain Evans observed, however, that the mutual effect of each compass on the other was a negative quadrantal effect, and he proposed to use such effect for compensation of the positive quadrantal error due to ship's magnetism. The proposition was studied mathematically by Archibald Smith * and the necessary rules were developed for the relative position of two similar compasses in order that their mutual interaction might compensate the ship's quadrantal error.

Now this whole matter becomes immediately comprehensible if we regard the effect of the correcting globe as that of a short magnetic needle of definite magnetic moment, dependent on the value of the magnetic intensity, directed along the line of resultant force. The globe becomes virtually an ideal frictionless needle.

Starting from the expression for the potential due to two globes magnetized by induction in the earth's field, we might determine the torque exerted upon a single or compound needle of any length, and we might show that the final expression was that due to two doublets (per globe) of given strength, the one directed tangentially, the other radially.

In order to preserve the conception of the doublet as equivalent to the globe, it is proposed to proceed by the converse method, viz.

(1) To replace each globe by a radial and a tangential doublet (omitting the vertical component as ineffective);
(2) To determine the torque due to a radial and to a tangential doublet; and
(3) To combine these results and arrive at the torque due to the globe or pair of globes.

Let $D = H r^3$ be the strength of the doublet in the direction of the meridian; then D may be resolved into the components:—

$$\left.\begin{array}{ll} \text{Tangential doublet} & D_t = D\cos\zeta \\ \text{Radial doublet} & D_r = D\sin\zeta \end{array}\right\} \quad . \quad . \quad (20)$$

where $\zeta$ is the azimuth of the ship's head.

We will determine the turning moment due to $D_t$ and $D_r$ from the torque exercised by a single magnetic pole, $m'$, placed at the centre of the globe.

Let us suppose that the needle is in the meridian, that the distance from centre of needle to centre of globe (or to $m'$) is $b$, and that the angle between the needle and the radial line $b$ is $\chi$ (for the one globe $\chi = \zeta + 3\pi/2$, for the other $\chi = \zeta + \pi/2$).

Let $m'\,T_1$ be the torque corresponding to the position of $m'$ at $b\,\chi$. Suppose $m'$ move through the angle $\hat{c}\,\chi$ so that the torque becomes

$$m'\left[T_1 + \frac{d\,T_1}{d\,\chi}\hat{c}\,\chi\right].$$

If then we have $+m'$ at $b$, $(\chi + \hat{c}\,\chi)$ and $-m'$ at $b$, $\chi$ the torque becomes

$$m'\frac{d\,T_1}{d\,\chi}\hat{c}\,\chi = [m'\,b\,\hat{c}\,\chi]\frac{1}{b}\cdot\frac{d\,T_1}{d\,\chi}.$$

Now, $m'\,b\,\hat{c}\,\chi$ represents the magnetic moment of a tangentially directed doublet; hence the torque due to $D_t$ will be

$$\frac{D\,t}{b}\cdot\frac{d\,T_1}{d\,\chi}.$$

Again, if $m'$ move to the position $\chi$, $(b + \hat{c}\,b)$, the torque becomes

$$m'\left[T_1 + \frac{d\,T_1}{d\,b}\hat{c}\,b\right].$$

Hence, if we have $+m'$ at $\chi$, $(b + \hat{c}\,b)$ and $-m'$ at $\chi$, $b$ the torque is

$$[m'\,\hat{c}\,b]\frac{d\,T_1}{d\,b}.$$

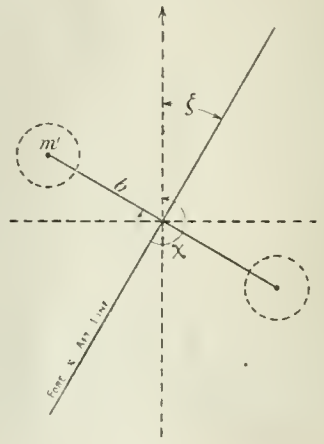



FIG. 25.

But $m'\,\hat{c}\,b$ is the magnetic moment of a radial doublet; hence the torque due to $D_r$ is

$$D_r\frac{d\,T_1}{d\,b}$$

and the torque due to one globe is

$$\frac{D_t}{b}\cdot\frac{d\,T_1}{d\,\chi} + D_r\cdot\frac{d\,T_1}{d\,b} \quad . \quad . \quad . \quad . \quad (21)$$

where $T_1$ is the expression for the turning moment on the needle, due to unit pole at $b$, $\chi$ [see (7) and (8)].

We are thus enabled to arrive at our result by making use of Archibald Smith's expressions.

If the needles be as long as 6 inches, we may have the ratio $a/b$ as great as $\frac{1}{4}$ and in some cases even greater, in which case it is desirable to take our expansions as far as terms involving $a^4/b^4$.

From (7), (8), and (21) we obtain for the torque on a single needle in the meridian due to a pair of globes,

* See A. SMITH, *Philosophical Transactions*, 1861, p. 174.

at distance $b$ from the needle centre, and when the ship's head is at $\zeta$, the somewhat lengthy expression

$$T=\frac{4\,a\,m}{b^3}\Big[2\,D_r\Big\{\Big(1+\frac{3}{4}\frac{a^2}{b^2}+\frac{45}{64}\frac{a^4}{b^4}\Big)\cos\zeta-\Big(\frac{15}{4}\frac{a^2}{b^2}+\frac{315}{128}\frac{a^4}{b^4}\Big)\cos 3\zeta+\frac{945}{128}\frac{a^4}{b^4}\cos 5\zeta\Big\}+D_t\Big\{\Big(1+\frac{3}{8}\frac{a^2}{b^2}+\frac{15}{64}\frac{a^4}{b^4}\Big)\sin\zeta-\Big(\frac{45}{8}\frac{a^2}{b^2}+\frac{315}{128}\frac{a^4}{b^4}\Big)\sin 3\zeta+\frac{1575}{128}\frac{a^4}{b^4}\sin 5\zeta\Big\}\Big].$$

In the case of a two-needle card, we substitute as before for $\cos\zeta$ the term $2\cos\alpha\cos\zeta$, and so on, and in the case of a four-needle card (if all four needles have equal pole strengths) for $\cos\zeta$ the term

$$4\cos\tfrac{1}{2}(\alpha_1+\alpha_2)\cos\tfrac{1}{2}(\alpha_1-\alpha_2)\cos\zeta$$

and so on [see (9) and (10)].

We must now insert the values of $D_r$ and $D_t$ [see (20)] and simplify the expression, and we arrive at the following result:—

For a two-needle card, the torque is

$$T=\frac{12\,H\,r^3\,a\,m}{b^3}[B_2\sin 2\zeta+B_4\sin 4\zeta+B_6\sin 6\zeta]\,.\quad(22)$$

where

$$B_2=\Big[1+\frac{5}{8}\frac{a^2}{b^2}+\frac{35}{64}\frac{a^4}{b^4}\Big]\cos\alpha+\Big[\frac{5}{8}\frac{a^2}{b^2}+\frac{105}{128}\frac{a^4}{b^4}\Big]\cos 3\alpha$$

$$B_4=-\Big[\frac{35}{8}\frac{a^2}{b^2}+\frac{315}{128}\frac{a^4}{b^4}\Big]\cos 3\alpha-\frac{105}{128}\frac{a^4}{b^4}\cos 5\alpha$$

$$B_6=\frac{1155}{128}\frac{a^4}{b^4}\cos 5\alpha$$

and similarly, in the case of the four-needle card.

If in the above we make $\alpha=0$, the two needles are situated in the centre of the card, and we have the expression for the single needle, remembering that in this case its magnetic moment is $4\,a\,m$.

We are now in a position to calculate the proportion of the octantal or dodecantal term in relation to the quadrantal value in any of the cases in which we are interested.

It is to be observed that the expressions for the torque are when the card is pointing in the meridian; in the following section, methods are described for experimentally measuring the torque at zero deviation by means of a torsion-head apparatus, and the measurements thus made are directly comparable and in complete agreement with the above theory.

As an example of the application of the foregoing, calculations have been made for the case of a two-needle card where $a/b=\frac{1}{4}$ and $\alpha$ has the values 0°, 15°, 30°, and 45°. (It is to be remembered that $2\,a$ is the diameter of the circle on which the needle poles are located, and, except in the single-needle case, is not the polar length of the needles.)

The results of the calculation are here tabulated:—

$a/b=1/4$.

| $\alpha$ | Coefficient of Quadrantal Term | Coefficient of Octantal Term | Coefficient of Dodecantal Term |
|---|---|---|---|
| 0° | 1·083 | −0·285 | 0·035 |
| 15° | 1·029 | −0·200 | 0·009 |
| 30° | 0·901 | 0·001 | −0·018 |
| 45° | 0·707 | 0·202 | −0·025 |

From these figures we conclude that with long needles resulting in the ratio $a/b$ being 0·25, we have, when $\alpha=0$, or in the single-needle case, an octantal term amounting to 26 per cent of the quadrantal, and a dodecantal term of over 3 per cent. When the poles are at 60°, the octantal and dodecantal terms are negligible. When the poles subtend 90°, the octantal term is 28 per cent of the quadrantal, the dodecantal being slightly over 3 per cent.

It will be readily understood that the rule previously given, for setting the needles when the actual distribution of magnetism in each needle is taken into account, applies equally to the elimination of the octantal as to the sextantal error.

## SECTION IV.

### The Testing of Compasses. Methods and Apparatus.

*Pivot friction.*—When we employ different methods for the measurement of pivot friction, we are liable to obtain results of considerable divergency.

This is in part due to the fact that the value of the friction depends upon the method of test; it has, for example, one value under static conditions, another value when there is small relative motion, a third apparent value under vibration, which, in some cases, may be very great indeed, and so on.

The static value of the frictional torque ($f$) may be determined by mounting the card on a graduated turntable provided with tangent screw and vernier, and after gently tapping, rotating the table, and observing the angle through which it must be rotated before the card frees itself and swings back towards the meridian.

If $\alpha$ be the angle through which the card is turned, $f=H\,M\,\alpha$, $f$ being in dyne-centimetres, $\alpha$ in radians, and H and M in C.G.S. units.

Again, if the card be allowed to swing over a small angle $\beta$ and we measure the work expended on pivot friction, we have $f_1=E/\beta$, where E is the work done in pivot friction in ergs.

Here we have a second definition of frictional torque, and the results obtained by the two methods of test differ materially.

The measurement of $f_1$ may be readily made as follows:—

If we take the potential energy of the card when in the meridian as a zero of reference, the potential energy when deflected through the angle $\theta$ is

$$H M (1-\cos \theta).$$

Suppose the card to be oscillating over a small angle, and $\theta_1$ and $\theta_2$ are two successive amplitudes on either side of the zero position; the loss of energy during the motion between the extreme positions is $H M [\cos \theta_2 - \cos \theta_1]$, or approximately $\frac{1}{2} H M (\theta_1^2 - \theta_2^2)$.

If we ensure that the loss of energy is due solely to pivot friction, e.g. by preventing eddy currents and air friction, we have

$$f_1 (\theta_1 + \theta_2) = \tfrac{1}{2} H M (\theta_1^2 - \theta_2^2),$$

hence

$$f_1 = \tfrac{1}{2} H M (\theta_1 - \theta_2).$$

We find that the angle $\alpha$ is materially greater than the angle $\frac{1}{2}(\theta_1 - \theta_2)$.

The angle of uncertainty due to friction is frequently measured by deflecting the card one or two degrees and allowing it to come to rest, when the zero error is observed. When applying this test, the experiment should be repeated a number of times and the maximum value of zero error recorded.

As would be expected, the test gives, in general, smaller angle-values than either $\alpha$ or $\frac{1}{2}(\theta_1 - \theta_2)$; but, as a measure of the angle of uncertainty, it probably more nearly approximates to normal working conditions than either of the former methods.

A rough workshop test frequently applied to dry cards is to deflect them 10° and observe the number of semi-oscillations before the card becomes stationary. If there be no loss of energy except that due to pivot friction, and if the magnetic moment be known, the test should give the value of $f_1$ approximately.

We have seen above that the decrement of amplitude per semi-oscillation is $2 f_1/(H M)$, so that if $f_1$ remains constant throughout, we have the same decrement in each half oscillation. The initial angle divided by the number of half oscillations may thus be taken as nearly representing the decrement of angle of amplitude per half cycle, hence the value of $f_1$.

It is a fact, however, that with the 10-in. dry card the loss of energy per oscillation due to air friction is considerable in relation to the loss from pivot friction, even when we are dealing with small angles such as 10°.

Mr. C. H. Wright finds for such a card of normal period the loss of energy in ergs, per semi-oscillation, may be expressed approximately as $5 A^2 + 0{\cdot}56 A$, A being the amplitude of the oscillation expressed in circular measure. Thus with a 10° swing the air loss and pivot loss are in the proportion of 1·6 : 1, nearly.

This test, therefore, while a useful one in the workshop, is not very sound scientifically.

Mr. Wright has found, as the result of a very large number of tests, that with good average points and jewels, and a standard 10-in. dry card:—

Angle $\alpha$ lies between 0·4° and 0·6°, and $f = 0{\cdot}4$ dyne-cm.
Angle $\frac{1}{2}(\theta_1 - \theta_2)$ is . . . 0·33°, and $f_1 = 0{\cdot}28$ „

Residual zero error lies between 0° and 0·15°.

Reference has been made to the fact that under vibration of certain kinds the apparent friction may be relatively large. For example, if a circular vibration in the horizontal plane be transmitted to the pivot, it appears that the conical sides of the pivot-tip rub against the walls of the jewel cup, in which case the frictional force acts at a much greater radius, giving rise to a large frictional torque.

If this be the explanation, we should expect the apparent friction to be less when the pivot is inverted and carried by the card and the cup supported on the fixed stem, than when the more usual arrangement is adopted. This expectation is realized in practice.

The following are the results of some rough tests made by myself in 1914, and communicated to the Compass Department of the Admiralty by letter dated December 1914.

Test on two aero compasses with (*a*) upright pivot, (*b*) inverted pivot.

| Cycles of Vibration per Minute | Character of Vibration | Deviation (*a*) c. | Deviation (*a*) c.c. | Deviation (*b*) c. | Deviation (*b*) c.c. |
|---|---|---|---|---|---|
| 650 | Nearly straight .. | 1° | 2° | 0 | 0 |
| 970 | Elliptical .. .. | 15° | 11° | 3° | 2° |
| 1,250 | Nearly circular .. | 12° | 10° | 5° | 3° |
| 1,600 | „ „ .. | 20° | 8° | 8° | 6° |

Amplitude of vibration about 1/16 inch.
Weight of cards in air { (*a*) 21 grammes. (*b*) 27 „
c. represents clockwise deviation.
c.c. represents counter-clockwise deviation.

The vibrating table used at the time was merely a temporary expedient, the vibrations being transmitted to it from a spindle carrying an unbalanced disc. A small bright ball was cemented to the surface of the compass bowl glass, and the nature of the vibration was observed from the apparent orbit of the bright spot seen in the surface of the ball when illuminated from a distant source of light.

An instance of marked friction due to vibration came to my notice in the case of a liquid compass recently supplied. The bowl was spring supported and in a position on the ship where considerable vibration existed. Under ordinary conditions the compass behaved quite normally and was entirely free of friction, but

at a certain speed the compass deviated fully 10° and remained steady at this deviation. It was suspected that the bowl was in a state of rapid circular vibration, the spring suspension was modified, and the trouble entirely cured.

This is a curious instance of an apparent effect of pivot friction being remedied by a modification of the spring suspension of the bowl.

It is now usual to support small compass cards likely to be subjected to heavy vibration on the inverted pivot principle.

Since the war, the quality of osmi-iridium obtainable for tipping the pivots appears to have deteriorated, the metal being insufficiently strong to withstand, without fracture, the shocks and jars which occur in practice in the use of liquid compasses. The Admiralty have therefore returned to the use of jewel points as used in very early compasses, except that an agate point working in a sapphire cup is recommended.

A few months ago the Admiralty published a short Manual on the subject of pivots for compasses; in it will be found a number of interesting micro-photographic enlargements of pivots which have fractured and worn. A certain shape of agate point and sapphire cup is recommended, but the pivot is too blunt for really good results. It seems to have been arrived at more from the point of view of strength than for its anti-frictional properties.

Owing to the small weight of the dry card, and to the fact that the pivot is not subject to jars and shocks as in the liquid compass, the osmi-iridium point in such cases is perhaps the more satisfactory of the two owing to its smaller frictional torque. The agate point will undoubtedly stand far more abuse without fracture than the osmi-iridium fine point as obtainable to-day.

It may be remarked that one of the outstanding features of pivot-friction tests is the inconsistency of the results obtained. It appears as if, even when considerable elaboration is resorted to in order to eliminate variables, the quantity we are measuring is inconstant.

### The Measurement of Magnetic Moment.

Figs. 26 and 27 illustrate an apparatus which I have found exceedingly useful for the rapid measurement of magnetic moments of small magnets and of compass cards. With it, the moment of a card in a liquid or dry bowl may be measured in C.G.S. units in the space of 1 minute, without removing the card from the bowl.

The apparatus consists of a glass jar inside which a needle arranged to be astatic in the earth's field is suspended from a torsion head. Each element of the needle has a strength of about 600 C.G.S. units, the elements being separated by about 10 cm. The lower one swings clear of the bottom of the jar and is immersed in damping fluid.

The system is accurately adjusted for astaticism by means of two small adjusting magnets supported by the central spindle, which magnets are capable of adjustment about a vertical and a horizontal axis respectively.

The spindle is supported on a fibre and controlled by a torsion spring, the ends of which are attached to the spindle and the torsion head respectively. The spindle carries a pointer which moves over a dial graduated to 360°, attached to and moving with the torsion head, but arranged to be independently rotatable, so that it can be set to zero when the torsion of the control spring is zero.

The jar is placed centrally on the compass-bowl glass, and in this position the lower element of the astatic combination comes within range of sensible force of the card needles.

The torsion head is rotated until the card is deflected into the E–W position. We then know that the

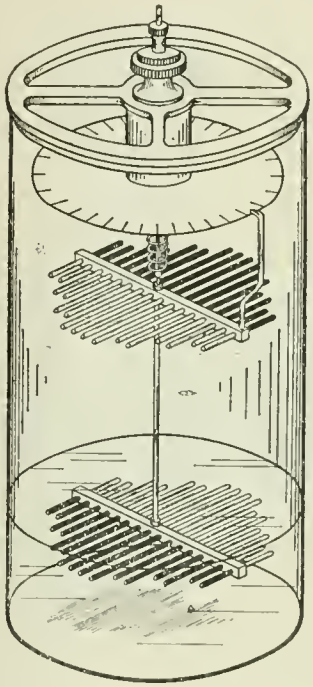


Fig. 26.—Torsion dynamometer for measuring magnetic moment.

earth is acting upon the card with a torque equal to H M, and since the astatic needle is co-axial with the card, the torques mutually exerted between the card and astatic system are also H M. This, however, is the only magnetic couple acting upon the astatic system, and it must therefore be balanced by the torsion of the control spring.

Since the one end of the spring is virtually attached to the dial, and the other to the pointer, the position of the pointer on the dial represents the amount of torsion of the spring. The torsion head may therefore be calibrated to read M direct for any place where H is known, it being understood that M is indicated on the dial when the torsion is such that the card under test is deflected into the E–W meridian.

Where a very powerful card is under test, it may be deflected by only 30°, in which case the readings of the torsion head must be doubled.

It will be observed that the accuracy of the device depends upon:—

(1) the astaticism of the system, which is readily tested and adjusted from time to time, and

(2) the calibration of the control spring.

It in no way depends upon the strength of the needles of the astatic system, or upon their distance from the card.

For the purpose of measuring moments of small magnets, the apparatus is completed by the addition of a special dry bowl and card (without magnets) provided with a cradle upon which any small magnet may be placed.

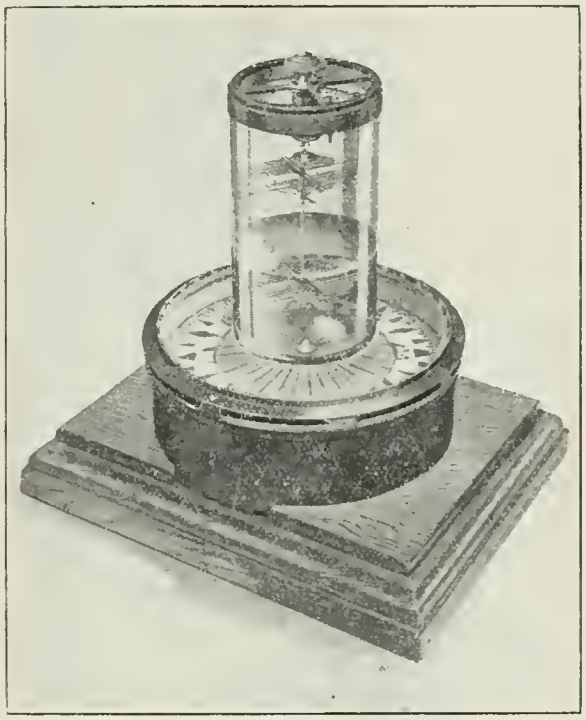


FIG. 27.—Torsion dynamometer with bowl.

The magnetic moment having been measured, the moment of inertia is most easily determined by calculation from the period of vibration.

With the apparatus described, the constants of a card may be far more readily determined than by the more usual method of first taking the period of vibration, adding a known moment of inertia, again taking the period and calculating the magnetic moment and moment of inertia from the observations taken.

### THE MAGNETIC BALANCE: AN APPARATUS FOR THE MEASUREMENT OF THE MAGNETIC DISTRIBUTION OF COMPASS NEEDLES.

We have already seen that we require to explore the distribution of magnetism on or in a needle, in order to determine the position of the poles. It has been indicated that if we can place each element of length of the needle in a uniform field and measure the force exerted on such element, we can in that way explore the distribution.

The apparatus about to be described is for the purpose of effecting this exploration. The distribution of the magnetism in magnets has been explored by various methods, all of which suffer from certain disabilities. The method to be described likewise has its shortcomings, but it is believed to offer advantages over those previously published, and is particularly applicable to straight magnetic needles of considerable length and small diameter as used in compass construction.

Referring to Fig. 8, if we take finite portions of two current sheets A B, C D, we shall have polar effects at the edges where the lines of force emerge from the space between the current sheets. To overcome this difficulty in a practicable apparatus, we employ two long concentric cylindrical current sheets, whose distance apart is small compared with the radius of curvature. If the current flows axially up one cylindrical

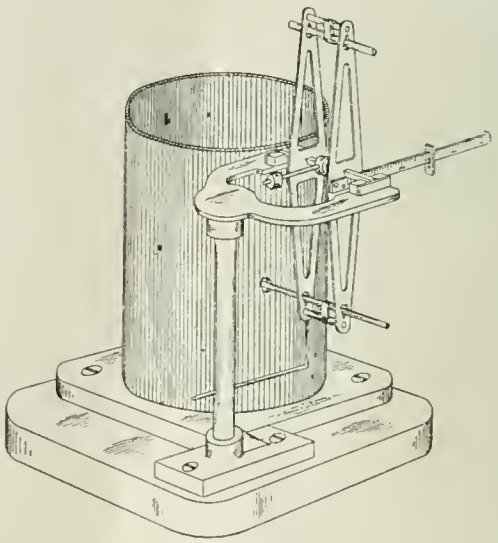


FIG. 28.—Practical form of distribution testing apparatus.

surface and down the other surface, and if the current density be uniform and equal in both, and of value $c$ absolute units per centimetre of periphery, we may say we have everywhere in the annular space between the cylinders a practically uniform field of density $4\pi c$, and no field elsewhere. The lines of force in the annulus are circles concentric with the axis of the cylinders and in planes at right angles thereto.

One form of apparatus is shown in Fig. 28. It will be seen that the two cylindrical current sheets are arranged about a vertical axis. They are formed by overwinding a length of brass tube with fine insulated wire, distributed as uniformly as possible.

The needle under test is carried in a cradle at the end of a vertical balance arm pivoted about a horizontal axis, and is so disposed that it passes in the radial direction through a small hole or through a narrow vertical slot cut in the tube, the wires being pressed to the sides of the hole or slot so as to skirt

round its edges. Thus the needle passes clean through the annular space between the current sheets, in which space a field exists at right angles to the pivotal axis of the balance.

The directive force of the earth produces no moment about the pivotal axis, but the interaction of the field due to the current sheets and the magnetic matter of the needle lying within the annular space produces a torque which may be counterbalanced by an adjustable rider sitting astride a horizontal rider-arm, as illustrated.

The needle is slidable along the cradle, so that different elements of it may be located within the annular space, while its weight is balanced by an adjustable counterweight carried on the opposite end of the vertical balance arm.

There are, however, two disturbing factors which complicate an otherwise extremely simple and attractive theory of the apparatus. First, the magnetic field bulges out beyond the cylindrical surfaces of the current sheets at the hole or slot; and, secondly, the density of magnetic matter is not uniform, even over the short length of the needle that is being acted upon.

That portion of the magnetic field beyond the cylindrical surfaces we shall call the "fringes." If we calculate the component of magnetic force at points on the horizontal axis (i.e. the magnetic axis of the needle) and normal thereto, we find the magnetic field extends to infinity in both directions, but as we travel away from the annulus the normal force rapidly decreases. If we take two points on the horizontal axis and find that the total flux beyond these points produces on the needle a negligible force, we may say such points are the limits of the effective fringes.

Let A B C D, E F G H be portions of two infinite current sheets with gaps at B C and F G. Current flows vertically up A B C D (i.e. out of the paper), and vertically down E F G H (i.e. into the paper). The direction of the field is indicated by the arrows.

X O X is the magnetic axis of the needle under test. O is the midpoint between the current sheets (Fig. 29).

$t$ = distance in centimetres between the current sheets.

$c$ = current density, i.e. current per centimetre measured transversely to the direction of flow.

$x$ = distance to a point on the axis X O X measured from O, positively to the right, negatively to the left.

B = field density between the current sheets everywhere except near the gap $= 4\pi c$.

B′ is the field density at $x$ in a direction normal to the axis X O X.

$\rho$ is the density of magnetic matter in the needle at the point O.

The fringing of the field will be symmetrical to the right-hand and left-hand sides of the current sheets; hence B′ will have the same value for $+x$ and $-x$.

It will be shown that the extent of the effective fringing is comparable with the width of the gap B C, and if this be small in relation to the length of needle, we may represent the magnetic distribution over the short portion of the needle within the limits of the fringes by the linear expression $\rho + b\,x$ ($b$ will have different values, for different tests, depending upon the portion of the needle under experiment).

If we consider two elements $\tilde{c}\,x$ of the needle situated respectively at $+x$ and $-x$, the force acting upon the combination will be

$$B'\,[(\rho + b\,x) + (\rho - b\,x)]\,\tilde{c}\,x = 2\,B'\,\rho\,\tilde{c}\,x$$

and the total force will be the integral of this between $x$ = the limit of fringing on the one side, and $x = 0$.

The total number of lines of force that cross the gap is manifestly equal to B $t$, and if we satisfy ourselves that the total number of lines of force of the fringes beyond the "limits" is a negligible quantity, we have for the force on the needle $\rho\,B\,t$; that is to say, the force is as if there were no fringing and the density of magnetic matter were $\rho$, provided only that the needle extends in both directions beyond the limits of effective fringing, and that we may express the magnetic distribution of the needle by the linear law over a length

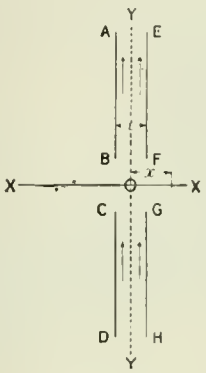



FIG. 29.

equal to that comprised between the limits of the fringes.

We will now consider the extent of the fringing action.

The effect of a simple gap B C is as if the current sheet A D were continuous and a current *strip* B C were superposed with current of density $c$, flowing in the opposite direction to that in A D. Similarly with regard to the gap F G.

Now, the field everywhere due to the continuous current sheets A D and E H is zero, except in the space between them, where it is $4\pi c$.

The field due to the interrupted sheets is therefore:—

($a$) in the outside space that due to the reversed current strips B C and F G only;

($b$) in the inside space that due to the reversed current strips B C and F G, plus the field $4\pi c$.

The force due to a current strip, as F G, at the point $z$, normal to the axis O′ Z, is simply $2c\theta$, where $\theta$ is in circular measure (Fig. 30).

When $z = 0$, the magnetic force $= 2\pi c$.

When $z$ is very great compared with 2 R, the magnetic force $= 4\ R\ c/z$ approximately.

In the case we have considered, the current density in sheet A D is assumed to have a constant value, $c$, from A to B and from C to D, and to be zero from B to C, and similarly in the case of the current sheet E H.

If, however, instead of assuming a strip of current to be actually missing from the sheet, we imagine the wires carrying the current to be merely pressed aside to both edges of the gap, we shall have no current actually missing from the sheet, but, on the other hand, that which is absent from the gap is concentrated at or near its edges.

Now, whatever the distribution of the wires may be in the neighbourhood of the gap, we may still consider we have a continuous current sheet of uniform current density, and a superposed current strip of non-uniform but definite current-density distribution, and we may call this current strip the "equivalent" strip. The "equivalent" strip is then a strip having such a distribution of current that, when it is superposed on the uniform current sheet, the resultant distribution represents that actually existing.

The distribution in the "equivalent' strip is obviously determined by the actual disposition of the

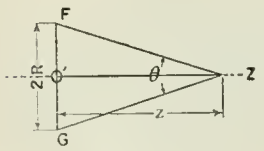



Fig. 30.

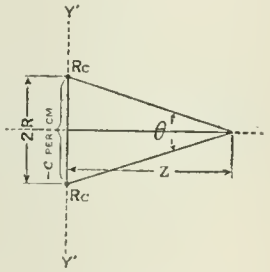



Fig. 31.

current-carrying wires, and this is to a large extent under our control. We can thus say that the fringes are due solely to the action of the "equivalent" current strips, and if we presuppose the disposition of the wires, we can calculate the values of the flux of the fringes.

If we take the width of the gap F G to be 2 R, and assume that wires which would normally pass over the gap are pressed to the side and are concentrated at the edges, the equivalent current strip is that shown in Fig. 31, viz. a strip of width 2 R with a uniform current density $-c$, and two wires at the extreme edges, each carrying a current of $Rc$ units.

The magnetic force at $z$ is

$$B''=2\,c\left[\theta-2\,R\,\frac{z}{z^2+R^2}\right]^{*} \quad . \quad . \quad . \quad (23)$$

which may be otherwise expressed as

$$2\,c\,[\theta-\sin\theta]$$

expanding sin $\theta$ we have again

$$2\,c\left[\frac{\theta^3}{\underline{|3}}-\frac{\theta^5}{\underline{|5}}+\text{etc.}\right]$$

* The direction of the flux B" in the fringe regions is the same as that of the flux between the current sheets.

When $\theta$ is small the first term only of the series is the important one, hence the force falls off very much more rapidly than in the instance of the straightforward gap where it is proportional to $\theta$ to the first power.

The following table shows the manner in which the normal flux density falls off in the two cases ($c$ being taken as unity) :—

(1) A current strip of width 2 R, with uniform current density, of unit value. (See second column of

Table showing Value of Fringe Flux Density in Two Cases.

| $z$ Value | $2\theta$ | B" [$z=x$] |
|---|---|---|
| 0 | 6·282 | 6·282 |
| 0·5 R | 4·430 | 2·830 |
| R | 3·142 | 1·142 |
| 1·5 R | 2·352 | 0·506 |
| 2·0 R | 1·854 | 0·254 |
| 2·5 R | 1·522 | 0·143 |
| 3·0 R | 1·287 | 0·087 |
| 3·5 R | 1·113 | 0·057 |
| 4·0 R | 0·98 | 0·0388 |

table.) The normal flux density when $z=0$ is 6·282, and when $z=$twice the width of strip the flux density is 0·98.

(2) The same as above, but with a current flowing

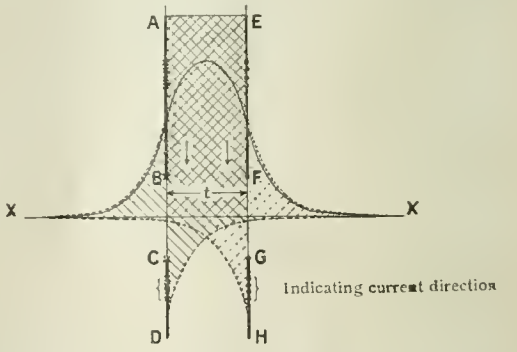



Fig. 32.

Flux distribution at points on axis X X (and at right angles thereto, i.e. in plane of paper as per arrows) due to current sheets A B C D, E F G H with gaps at B C and F G.

Current density uniform in sheets except at edges of gaps, viz. at B, C, F, G, where current missing at the gap is concentrated.
Current flows into the paper in A D and out in E H.
Area shaded ◇◇◇ .. .. .. .. Flux density distribution of uninterrupted current sheets.
Area shaded \\\\ and //// .. Distribution due to the equivalent current strips B C and F G.
Full line curve . .. .. .. .. .. Resultant distribution of interrupted current sheets.
Gaps B C and F G are both equal to $t$.

along each edge of the strip in the reverse direction, of value R (corresponding to the case where the wires are pressed to the edges of the gaps)—see third column of table.

In this case we start with the same flux density when $z=0$; but when $z=$twice the width of strip it has fallen to 0·0388.

Case II is that which most particularly interests us. Fig. 32 represents the flux distribution in this case, where the distance, $t$, between the current sheets equals the gap width, or 2 R. It would appear that with these proportions and with the magnetic needles experimented with, it is sufficiently accurate to take the limit (L) of effective fringing as equal to 3 R; i.e. we assume the fringes end, for all practical purposes, at a distance from the current sheets equal to $1\frac{1}{2}$ times the gap width.

If we integrate expression (23) with respect to $z$ we obtain $\int B'' dz = 2c\theta z$.* From this we see that the total flux in the fringe between $z=\infty$ and $z=3$ R is less than $0{\cdot}14\,R\,c$. Since $t=2$ R, the total flux $B\,t=8\pi c$ R; hence, in neglecting the fringe flux beyond the limits $z=3$ R, we are neglecting about 1 per cent of the total flux.

Expression (23) may further be expanded in the

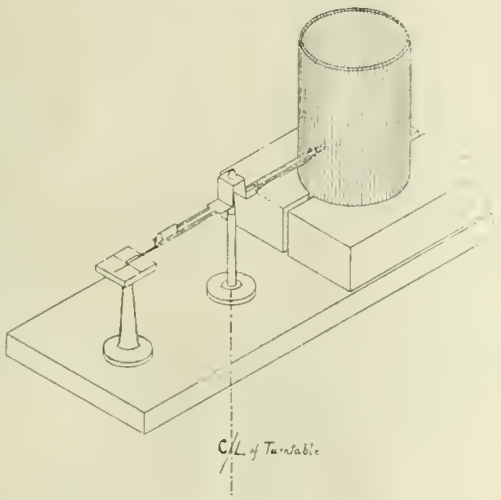



FIG. 33.—Magnetic balance for ascertaining distribution.

form of two series, the one applicable when $z < R$, the other when $z > R$; thus,

$$\text{when } z>R,\ B''=4c\left[\frac{2}{3}\frac{R^3}{z^3}-\frac{4}{5}\frac{R^5}{z^5}+\frac{6}{7}\frac{R^7}{z^7}-\text{etc.}\right],$$

so that when the ratio $R^2/z^2$ is negligible in comparison with unity we have

$$B''=\frac{8c}{3}\frac{R^3}{z^3}.$$

We may thus extend the above table, and assuming an approximately correct distribution of magnetic matter on the needle under test, we may imagine it acted upon by the flux distribution B″. In this way we may satisfy ourselves that the total force exerted on the needle by the flux lying beyond the limits $z=3$ R is within the frictional limit of our apparatus and may be neglected. Given a suitably designed apparatus, we are enabled to measure the density of magnetic matter in the needle up to abont 7 mm. from the end; for points nearer to the ends it is necessary to apply a correction owing to the fact that the needle no longer extends beyond the limit of effective fringing.

From the foregoing the manner of applying the necessary correction will be readily understood. The following figures give the results of the calculations. $x_1$ being the $x$-value, measured from O, of the end of the needle (see Fig. 29).

Taking the case where $2\,R=t$, or the gap width is equal to the distance between current sheets, we find that when $x_1=3$ R, i.e. the needle end projects beyond the current sheet a distance equal to the gap width, the force measured is $\rho\ B\ t\ (1-k)$, where $k$ is less than 0·03.

When $x_1=2$ R, i.e. the needle end projects by one-half the gap width, $k$ is under 0·07.

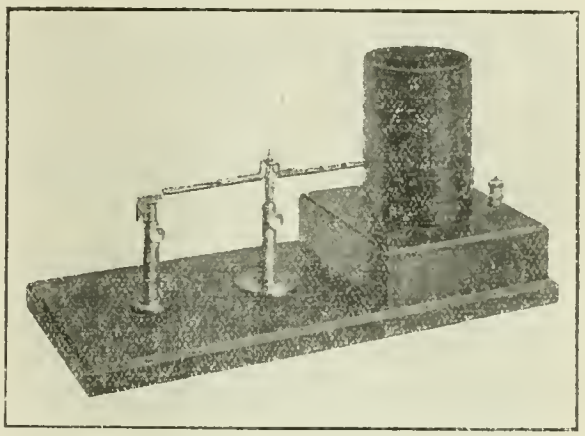


FIG. 34.—Magnetic balance.

When $x_1=$R, i.e. the needle end is flush with the current strip, $k$ is probably under 0·25.

When $x_1=0$, i.e. the needle end projects only to the mid-point between the current sheets, the value of $k$ is somewhat indefinite, but it would appear it may be as much as 0·7. In this case, only half the flux acts upon the needle.

It will be seen from the curves Fig. 35 that the density of magnetic matter rises very rapidly near the extreme ends of the needle.

In the experimental apparatus used

$$\left.\begin{matrix}2\,R=3{\cdot}5\text{ mm.}\\ t=3{\cdot}5\text{ mm.}\end{matrix}\right\}\text{ approximately.}$$

An alternative apparatus for performing these measurements is illustrated in Figs. 33 and 34, where the force exerted on the element of the needle under test is balanced against the earth's directive force on the whole needle.

If $l$ be the distance from O to the pivotal axis of

* If we differentiate $2c(\theta z)$ with respect to $z$ we obtain B″.

$$\frac{d(\theta z)}{dz}=\theta+z\frac{d\theta}{dz};\ \text{and}\ \frac{d\theta}{dz}=\frac{-2R}{z^2+R^2}=\frac{-\sin\theta}{z}$$

therefore $$2c\frac{d(\theta z)}{dz}=2c[\theta-\sin\theta]=B''$$

the needle, the torque due to the current sheets about the pivotal axis may be shown to be

$$\rho \, \mathrm{B} \, t \, l + b \int_{-(\frac{1}{2}t+\mathrm{L})}^{\frac{1}{2}t+\mathrm{L}} \mathrm{B}' \, x^2 \, d \, x$$

provided that the needle projects through the further fringe region. L represents the limit of fringing measured from the current sheet, and may be taken for the present purpose as 3 R.

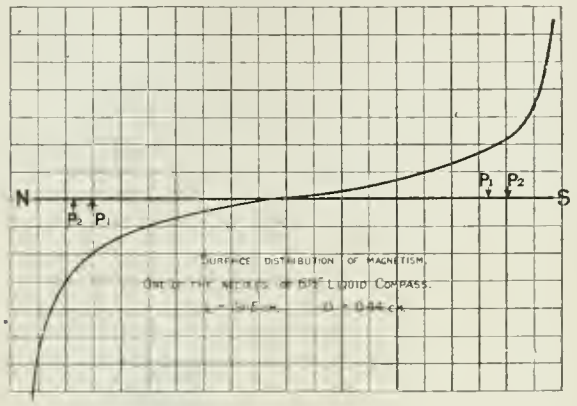



FIG. 35*a*.

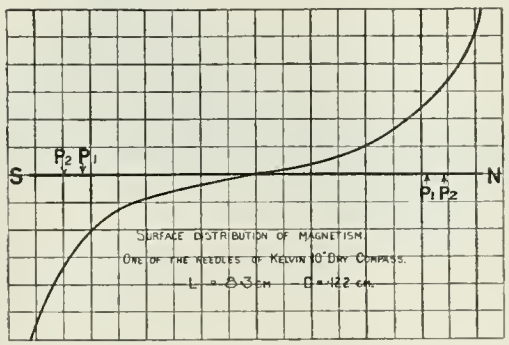



FIG. 35*b*.

It may further be shown that

$$\int_{-(\frac{1}{2}t+\mathrm{L})}^{\frac{1}{2}t+\mathrm{L}} \mathrm{B}' \, x^2 \, d \, x = \frac{\mathrm{B} \, t^3}{12} + 4 \, t \int_0^{\mathrm{L}} \mathrm{B}'' \, z \, d \, z$$

where B″ is the flux density due to a single current strip, and $z$ the distance measured from such current sheet. B″ is given by (23) [see also Fig. 31].

By differentiation, we see that

$$\int \mathrm{B}'' \, z \, d \, z = 2 \, c \, [\tfrac{1}{2} \, \theta \, (z^2 - \mathrm{R}^2) - \mathrm{R} z],$$

hence

$$\int_0^{\mathrm{L}} \mathrm{B}'' \, z \, d \, z = 2 \cdot 3 \, \mathrm{R}^2 \, c.$$

The expression for the torque then becomes

$$\rho \, \mathrm{B} \, t \, l \left[ 1 + \frac{b \, t}{\rho} \left( \frac{1}{12} \frac{t}{l} + \frac{2 \cdot 3}{\pi} \frac{\mathrm{R}^2}{l \, t} \right) \right].$$

In the experimental apparatus $t = 2 \, \mathrm{R} = 0 \cdot 03 \, l$, and if we take $b \, t / \rho$ as less than unity, as will be seen (from the curves) to be the case except at the immediate end of the needle, we have

$$\text{Torque} = \rho \, \mathrm{B} \, t \, l \, (1 + k),$$

where $k$ is less than 0·01.

We are therefore sufficiently correct in neglecting this correction in a suitably designed apparatus.

The needle as a whole will be acted upon by the earth's field, and the torque due to this field will be H M sin $\theta$, where $\theta$ is the angle the needle makes with the meridian. If then the whole apparatus be turned in azimuth until balance is obtained, if $\theta$ be observed and if H and M be known, we have

$$\rho = \frac{\mathrm{H} \, \mathrm{M} \sin \theta}{4 \, \pi \, c \, t \, l}.$$

For points near the end of the needle the necessary correction is somewhat more laborious than in the previous case, but it is only very slightly larger.

In the apparatus described, the maximum value of the magnetic force in the annulus does not exceed five times the value of the earth's horizontal force.

Fig. 35 shows the distribution in the cases of two typical magnetic needles as used in compass-card construction.

(*a*) represents a needle 9·5 cm. × 0·44 cm. used in the standard Naval liquid bowl.

(*b*) represents a needle 8·3 cm. × 0·122 cm. used in a 10-in. dry card.

The positions of the poles * are indicated at the points marked $p_1$, while the positions are also indicated of the $p_2$ points determined by the relation

$$a_2 = \sqrt{\left( \frac{\Sigma \, x^3 \, \rho \, d \, x}{a \, m} \right)}.$$

## The Measurement of Sextantal and Octantal Effects.

It is to be observed that both sextantal and octantal effects arise from the same causes, viz. length of needle, and non-uniformity of the deflecting field. The two

* It is interesting to note that since the $p_1$ points are the centres of gravity of the magnetic matter, we ought to be able to determine their location by simple observations involving the measurement of torque only.

Referring to Fig. 8, imagine that the current sheets are so far separated that one-half of the needle may be immersed in a uniform field of strength H′. Let $m$ be the quantity of magnetic matter on the half needle, and let the needle be pivoted about a point O in the prolongation of the axis.

The torque about O will be H′ $m \, l$, where $l$ is the distance from O to the centre of gravity. Now shift the pivot along the axis by one centimetre, the needle still being immersed in the field to half its length. The torque will now be H′ $m \, (l \pm 1)$, and the difference between the two measurements gives us the value of H′ $m$. Applying this to either of the two observations, we arrive at the value of $l$ directly.

The apparatus already described may be modified for this purpose. Imagine a channel cut axially (i.e. vertically) between the current sheets in Fig. 34, so that half the needle may be inserted between them (vertically). We may then assume with sufficient accuracy that this portion of the needle is in practically a uniform field.

Further, by immersing the needle in the uniform field to varying depths and suspending it so that it is capable of rotation about a vertical axis, say one coinciding with the axis of the cylinders, we may measure the total amount of magnetic matter on any portion of the needle extending from one extremity towards the centre, and this provides an additional method of arriving at the distribution of magnetic matter along the needle.

This method may be found to be preferable to those already described, since the total magnetic matter on the half needle is directly measured, and thus the element of doubt due to the uncertainty of values near the extreme end is eliminated.

effects are interdependent; if we adopt an arrangement of needles which eliminates the sextantal effect, we similarly obtain negligible octantal effect.

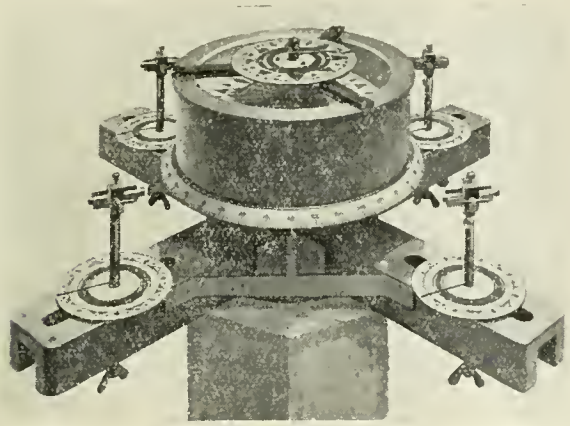


Fig. 36.—Apparatus for measuring sextantal or octantal effect.

The semicircular, quadrantal, sextantal, and octantal deviations form the first four terms of the Fourier's Series, the first and third appearing together, as also the second and fourth.

The apparatus illustrated in Fig. 36 has been designed for permitting the sextantal or octantal effect of any card or arrangement of needles to be readily measured. It consists of a bowl in which the card is pivoted, surrounded by a rotatable turntable, suitably graduated in degrees. The turntable is provided with four

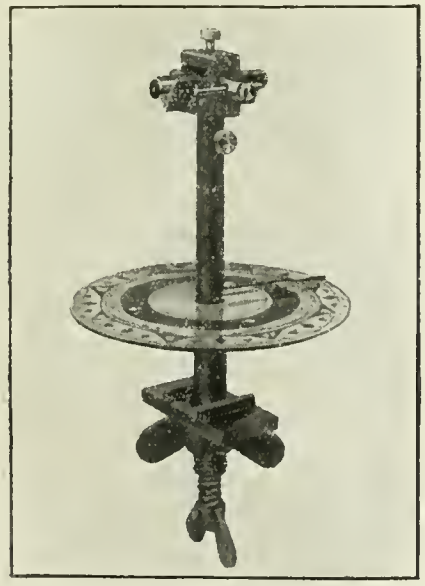


Fig. 37.—Theoretical globe.

arms which may carry quadrantal globes or magnets, the distances from the axis of the apparatus being adjustable.

Suppose two spheres be arranged on a diameter. As the turntable is rotated through known angles, the deflection of the card due to quadrantal effect, etc., may be noted, and its relation to the angle which the line joining the sphere centres makes with the meridian may be plotted.

Alternatively, the card may be controlled by a torsion head, and always brought back to the meridian, in which case we measure the torque exerted on the card when in the meridian by the action of the globes.

I prefer this method where possible, and one portion of the apparatus accordingly consists of a dummy (non-magnetic) card arranged for torsion-head control, and provided with cradles upon which needles may be placed of varying length and at various distances from the axis. In this way a new disposition of card needles may be tested for octantal effect in a few minutes. With existing cards, it may not be convenient to alter them for torsion-head control, in which case the deflection method must be resorted to.

Fig. 38. Fig. 39.

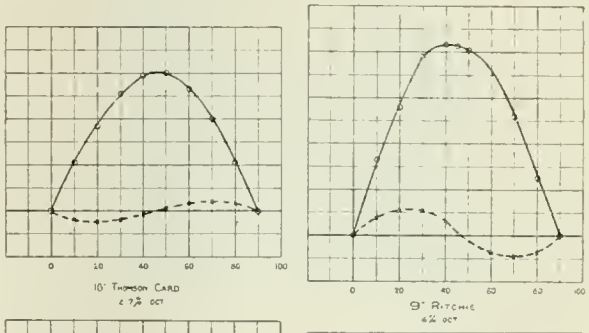


Fig. 40. Fig. 41.

When using globes for the purpose of applying this test, we measure the combination of true quadrantal and inductive effects, also that due to sub-permanent magnetism and to any irregularity in the globes themselves. In order to study the octantal effect, it is better to use "theoretical" globes which, while producing the requisite quadrantal deviation, are incapable of induction or sub-permanent magnetism.

Now, we can do this by substituting for the globe a very short magnet, to imitate a doublet, provided we keep the axis of same always in the meridian.

Fig. 37 represents the "theoretical globe" recommended for this purpose.

A short magnet is carried in a V-cradle at the upper end of a pillar, so as to come into the plane of the card. The pillar is rotatable about the vertical axis, and is

provided with a pointer moving over a graduated dial attached to the arm of the turntable, so that, as the turntable is rotated through any known angle, the imitation doublet may be rotated back through the same angle, thus preserving its alignment in the meridian.

When using two "theoretical globes," it is important that they are of the same size; in other words, the imitation doublets must have the same horizontal magnetic moment. They are accordingly provided with an adjustment in the shape of a small auxiliary magnet capable of rotation about a horizontal axis.

The one pillar with its magnet is placed at a certain distance from the card, and the deviation noted; the second pillar is then substituted, and the adjusting magnet manipulated until a similar strength is obtained. Clearly, any vertical component which the imitation doublet may possess due to the final position of the adjusting magnet produces only vertical force at the card and cannot affect its deviation.

If these imitation doublets be sufficiently good imitations, the torque on the card is given by expression (22), and if plotted, the octantal effect may be separated.

It will be noticed, however, that the torque is of the form

$$B_2 \sin 2\zeta + B_4 \sin 4\zeta + \ldots$$

If, then, we use four equal doublets instead of two, arranging them on diameters at right angles, the first term will disappear and the second will be doubled; in other words, we separate out the octantal effect directly.

The method of test recommended is first to employ four doublets and measure the amplitude of the octantal term, then remove two, and again take a measurement on a quadrantal point; a comparison of the two readings at once provides the measure of the octantal in terms of the quadrantal effect.

If we arrange the doublets either tangentially or radially and let them rotate with the turntable, without resetting them in the meridian before each observation, we obtain a semicircular plus a sextantal effect, and by a suitable disposition of the doublets we may eliminate the semicircular, leaving only the sextantal effect.

This method is, however, less direct, and hence less to be preferred than that given above.

Figs. 38 and 39 show measurements of the octantal effect in two typical cases. Figs. 40, 41, and 42 represent the effects obtained from 6-inch magnets; Figs. 41 and 42 illustrate the octantal terms when the poles are located at 90°; Fig. 40, when the two needles are brought together at the centre.

In all cases the octantal effect is, as explained, by the process of measurement, to twice the scale of the

QUADRANTAL AND OCTANTAL DEVIATION.

6″ Needles. Poles subtending Angle of 90°.

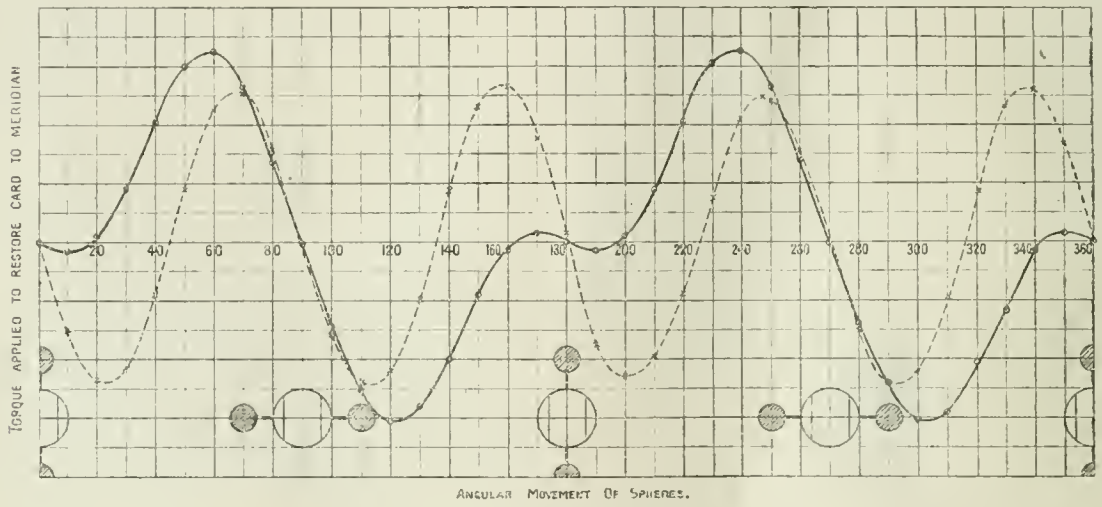



FIG. 42.

"total" effect. Octantal effects are drawn dotted. "total" effect, i.e. quadrantal and octantal, etc., in full lines.

The doublets are located 12 inches from the axis.

Fig. 42 shows the "total" and "octantal" effects in the four quadrants. The presence of the dodecantal term is plainly exhibited.

### THE EFFECT OF MAGNETIC DISSYMMETRY OF THE CARD.

Lord Kelvin frequently described the ideal magnet as "an infinitely thin, straight, uniformly and longitudinally magnetized rod," and we may almost read this definition in his choice of magnets for his compass card. He further considered any bar magnet, no matter what the nature of the magnetization, as a definite combination of such magnetized filaments.

We may thus consider a rod badly and non-uniformly magnetized as represented by a certain arrangement of longitudinal filaments and a certain arrangement of transverse filaments; in other words, a certain

magnetic moment directed longitudinally plus a given magnetic moment directed transversely.

Each filament tends to set itself along the direction of the resultant force. Hence, the smaller the transverse dimensions, the less will be the tendency of the needle as a whole to depart from the " true " direction, due to imperfect magnetization.

We will assume that the thickness of the needle is sufficiently small to rule out any cross-magnetization effects, and we then see that the needle will point " true " in a uniform field whether the magnetic distribution be symmetrical about the central transverse plane or not.

Again, consider a two-needle card as in Fig. 11, and suppose one needle is considerably stronger than the other; each needle will tend to point " true " and the card, as a whole, will exhibit no untoward tendency in a uniform magnetic field.

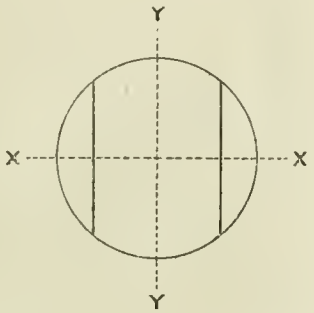



Fig. 43.

This is not, however, the case when the directing field is non-uniform. Then we again find deviations arising from both kinds of dissymmetry, viz.

(*a*) Longitudinal dissymmetry of either or both needles about the plane X X (Fig. 43);
(*b*) Lateral dissymmetry about the plane Y Y, i.e one needle being stronger than the other.

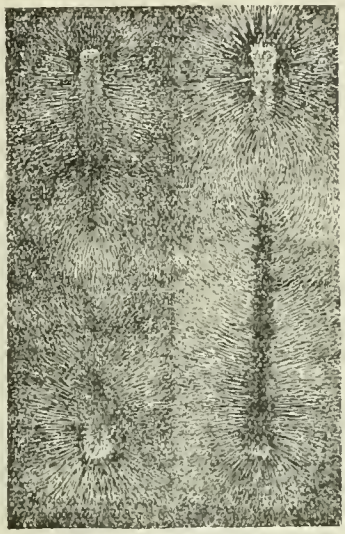
Elaborate tests are frequently applied by the purchaser to determine whether his card is pointing " true," but always in a uniform field, and, as far as I am aware, no tests are ever applied which can possibly exhibit the effects of dissymmetry, if such exists.

I do not wish to lay undue stress on these effects but it is as well to bear in mind the biblical warning against straining at a gnat and swallowing a camel.

An interesting case of dissymmetry appearing after careful magnetization is illustrated in Fig. 44, which represents the iron-filing diagrams obtained from a special bar submitted recently for test as a specially good one, (*a*) shortly after magnetization, (*b*) after a lapse of six weeks. One has to account for such a poor specimen as a " war-product "—unfortunately one of many examples of " war-products."

It is easy to see the nature of the effect which is attributable to this kind of dissymmetry, but as we must presuppose some definite and fortuitous irregularity, it is perhaps better to test for such irregularity on the turntable in the manner hereafter explained.

The second class of dissymmetry is more important. Let us assume that the magnets themselves are symmetrically magnetized, but that one is stronger than the other. We may substitute for such a system a symmetrical arrangement with an additional single needle of definite strength, coincident with one of the pair. The problem is thus reduced to the determination of the characteristics of a single needle displaced from the axis, in a non-uniform field (see Fig. 45).



*a* *b*

Fig. 44.—Change of distribution with time.

The torque on the one end of the needle, $+m$, due to the pole $m'$ is of the form

$$m' m [A_1 \sin(\zeta - \alpha) + A_2 \sin 2(\zeta - \alpha) + A_3 \sin 3(\zeta - \alpha) + \text{etc.}]$$

and on both ends we have

$$2 m' m [A_1 \cos \alpha \sin \zeta - A_2 \sin 2\alpha \cos 2\zeta + A_3 \cos 3\alpha \sin 3\zeta - \text{etc.}]$$

If now $\alpha = 30°$ the sextantal term disappears, as before, but there remains a cosine-quadrantal term which is entirely objectionable.

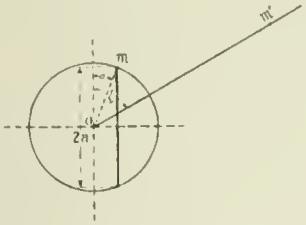



Fig. 45.

If now we apply a second pole, $+m'$, symmetrically placed, opposite to the first, the torque becomes

$$4 m' m A_2 \sin 2\alpha \cos 2\zeta,$$

and if we make $\alpha = 0$, that is, if we eliminate dissymmetry, the torque vanishes.

We may therefore test for dissymmetry by applying two equal imitation doublets directed, say, radially,

situated symmetrically on a diameter and opposing one another. There should then be no deviation of the card on rotating the turntable. The same arrangement will also detect dissymmetry of the first order.

It will be appreciated that in the commercial manufacture of compass cards all defects arising from length of needle, inductive action, inaccuracy of disposition, magnetic dissymmetry, etc., become less and less important as the needles are made shorter.

In conclusion, I desire to express my indebtedness to Mrs. and Mr. F. A. King, and Messrs. C. H. Wright and H. A. Stevenson, for the very kind help they have afforded me in the preparation of this lecture, but for which it would never have been given.

# DISCUSSION ON

## "PLANNING A WORKS RESEARCH ORGANIZATION."*

North-Eastern Centre, at Newcastle, 20 January, 1919.

**Sir George Hadcock**: The paper has come at a very opportune moment, when reorganization is in the air, and experimental and research work is naturally being considered in practically all industries. I was hoping that the author would have given his views as to the relative merits of co-operative central laboratories and independent laboratories. No doubt members have been impressed by the photographs of the splendid buildings in which America and other countries have housed their research laboratories, but I think we need not be discouraged by the want of these palatial buildings in England, because although they are desirable they are by no means necessary, and much important and useful research work has been done in far more modest buildings. When one considers the cost of these huge laboratories I am afraid that no Board of Directors would pass an expenditure of this nature at the present time. Naturally, if co-operative laboratories find favour and a number of firms join together to equip such an institution, the cost to each individual firm may be moderate. From one point of view the co-operative system is excellent, but in order that every firm belonging to it shall obtain the highest efficiency, it may be necessary for them to disclose their methods of manufacture, etc. In an age of competition such as we may now have to look forward to, it is evident that manufacturers will not be anxious to place their discoveries at the disposal of their rivals.

**Dr. A. C. Michie**: I agree with the author that the automatic sprinkler type of fire extinguisher may prove decidedly awkward under certain conditions. There is no universal fire extinguisher which would prove suitable in many cases which might arise in a research laboratory. Buckets of clean sand are frequently more useful than water. The efficiency of most laboratories could be greatly increased if more provision were made for the proper storing, in a room apart from the working laboratories, of all apparatus which is not in frequent use. One has always to build up, in the course of experimental work, a large number of pieces of apparatus which take much time and care in designing and assembling, but which may not be required again for a considerable time. These should be removed, if possible, out of the working laboratory and properly stored, arranged, and catalogued so that when the time comes the apparatus with the necessary data for its use is readily available. Much time would thereby be saved and greater use could be made of the laboratory itself.

**Mr. H. W. Clothier**: Whilst acknowledging the necessity for reform and admiring the elaborate plans described by the author, it is well to remember the large amount of research work that has been done without ostentatious buildings in the past by manufacturers in this country. Sir George Hadcock has voiced an opinion on his experience in respect to a large firm which I am able to confirm for a comparatively small works. A research building might easily become a "white elephant." All works specializing in switchgear have a quantity of apparatus for normal routine testing. Our future depends upon the training of men with initiative and inspiration, but we must try to avoid splitting up our organization into too many independent and watertight compartments. It is a significant fact that without elaborate research organization British specialists have produced apparatus which excels that from America, and this should be attributed to something more than good luck. Is it not because the English system, being more flexible, gives greater scope to individual initiative? There is scope for central or district research laboratories to which manufacturers and others could refer for specific information and for special research. At the present time it would be a great advantage to have a co-ordinate research on the breaking capacities of switches. It would be difficult for any manufacturer working alone to carry out a research of this nature, on account of the large amount of power required.

**Mr. S. S. Cook**: It is satisfactory to note the increasing recognition of the importance of research work. Research work has to my mind a double recom-

* Paper by Mr. A. P. M. Fleming (see page 153).

mendation, like virtue it is its own reward and, like honesty, as is now being realized more and more, it pays. In my attitude towards the paper I find more of agreement than criticism. I am in agreement with Sir George Hadcock's opinion that a good deal of useful research work can be and has been carried out in the past with modest apparatus. The method hitherto followed by most firms who have undertaken research work in connection with their business is to make special provision for each particular research, but for general work of this nature I think that the author is right in advocating the separate building. I have been for many years associated with research work and, from my experience, if I may state an apparent truism, there is nothing cramps research work so much as want of room, and it seems to me the first requirement for an industrial concern intending to start a research department or intending to extend the scope of its researches—and, I take it, it is that kind of firm for which the paper has been written—is a building of such proportions as will give ample accommodation for the tools and experimental apparatus likely to be needed, and offices for the experimental staff and draughtsmen. I do not think, however, they would be justified in making provision on the lines of the author's classification, which is, in my opinion, too elaborate to have the necessary elasticity. Any firm in this position would probably have a few investigations immediately necessary, and I would suggest that they start from these as a basis. For these investigations they could make all the provision that they foresee to be necessary, on an ample scale; and this provision, with a margin of say 100 per cent, or perhaps even more, for unforeseen requirements of additional research in the future, would determine for them the scale of the building and office equipment. In this connection I am interested to note that on the lantern slide which the author has shown of the curve of growth of work in a typical research department the increase is at the rate of about 100 per cent in every four years. But I would not recommend installing any further plant than that which these concrete programmes require. Other objects of research would undoubtedly present themselves, and provision for these would be made as it was required, and the research department would grow by a process of evolution. There would be no accumulation of useless plant except such as had already served its purpose and could be written off. It seems to me unnecessary to include a costs office in such an establishment. A manufacturing firm such as we are considering would already have a costs department in full working efficiency, and all the work of that nature would best be done there. The director of the research department should, of course, be allowed full access to all accounts relating to his department. To provide the means for any research before its objective is formulated would lead to aimless desultory work, and this should certainly be avoided, as it will be, I think, in proceeding on the lines I suggest. As the author has mentioned, no two firms would have identical requirements in respect of such work, but as illustrations of how the problem has been worked out in some instances, the installations which he mentioned are both interesting and instructive, and the conclusions he has given regarding lighting, ventilation, supplies, and many other points merit the most careful consideration.

**Mr. E. Fawssett**: It would save much duplication of work if manufacturers could submit all their problems to one central recognized authority, completely impartial, but such a scheme seems impossible of realization with human nature what it is; consequently the works' own organization must collect all the latest information, and even then they only have access to that already published, and are therefore so much behind the actual knowledge on the subject. In connection with the author's classification of laboratories there is, I consider, great need for a research institution on the lines of (3) and (4) on the North-East coast, especially to deal with electrical problems requiring expensive equipment, the use factor of which could then be far greater than if any one undertaking attempted to equip such a laboratory for itself. I consider the section on the "Staff" to be exceptionally well written: it shows exact appreciation of the needs of a laboratory, and the limitations and disabilities commonly met with. I would emphasize the considerable field for "resourceful, well-trained, energetic," but distinctly ordinary men, and the limitations of the man of genius in industrial work. A liberal proportion of workshop experience should be a *sine qua non* for all the technical employees. The paper will be well justified if the author can thereby so impress the final sentence of this section on those responsible for fixing salaries, that the technical man may at last get his reward commensurate with his contribution to the success of the undertaking. It is difficult to criticize the plans without further knowledge of their intended use. If, however, the amount of land occupied is not a ruling factor, I should much prefer the single-story type up to much larger areas than he advocates, and would go in for top and side lighting on account of its much better general distribution. Almost all the plans provide a ladies' rest-room as in works where considerable physical effort is required. If this is necessary, it seems only fair to provide some counterpart for the men; perhaps the library or conference room is intended to meet this. In most of the smaller designs the electrical section appears to be absurdly cramped, and not till we get to Fig. 14 is there a really sufficient general electrical experimental room, and even this, being on the first floor, can scarcely deal with many of the heavier problems that could not well be tackled in the works proper. It seems to me that in any works manufacturing heavy machinery or cables a special building with top lighting, electrically operated crane, full range of supplies, and access to all the best instruments in the laboratory is a necessity. In most of the plans submitted the machine room appears to be altogether inadequate. Finally, I consider we ought to steer a middle course between the rather over-developed barrack laboratories of America and the present happy-go-lucky methods too evident in this country.

**Mr. R. M. Longman**: It appears to me that the cost of research laboratories would provide a good and proper means for the disposal of some of the excess

war profits. I am of opinion that routine testing should also be done by the research organization. It helps largely to pay for the cost of the laboratory and shows up the weak points of the various apparatus to be tested, and these may be the subject of some little further investigation. The author has rightly emphasized the importance of keeping adequate records of all work undertaken. Unless such full records are made at the time, it is most difficult to gather up the threads, even after a comparatively short interval. We, in this country, are far too conservative and secretive with regard to work and investigations which have been carried out. There has been far too little publicity, and it really is very disconcerting, after spending considerable time on some investigation, to find in casual conversation with other people that exactly the same work has been carried on by them at, perhaps, a much earlier period. It undoubtedly has led to very great waste of time and energy, and thus stifled progress. Referring to the paragraph on "Technical Processes," there seems to be a great need for issuing proper instructions for the setting up and maintenance of quite new gear and apparatus; undoubtedly several cases have occurred in which new gear has been condemned simply because it has not received proper attention, due to the want of thorough instructions. The author has referred on one or two occasions to the limited supply of research workers. Undoubtedly this has been due to the very poor pay offered them in the past. Many good university men who would have preferred research work have even gone into the teaching profession, which is notoriously badly paid. Others, to obtain such appointments, have in many cases been obliged to leave the country. Such Colonial appointments are undoubtedly better paid than the Home ones have been. Further, many firms and undertakings, even Government departments, have built and equipped good laboratories and test rooms, and then ruined the job by offering inadequate salaries. I also wish to refer to the practice which is generally followed by technical institutions and universities of offering two or three of the best students, on the completion of their course, senior studentships or research scholarships for a further period of one or two years. This I believe is the wrong plan, gives poor results, and means a waste of opportunities. It would be much better to throw these opportunities open to men who have left the college two or three years and who would then have a definite research to engage upon, be much better prepared for it, and their employer would or should be only too glad to assist in every way possible and would pay the salary during such work. It should also do much to improve the relations between colleges, etc., and works.

**Mr. T. Carter**: I should like to ask the author a question about routine testing. In the case, for example, of cotton-covered copper wire, the two extremes in testing would be either to check every delivery for conductivity, or, on the other hand, merely to measure the size and trust to the supplier to send the correct quality. What does the author consider, as a result of his experience, to be the correct intermediate position to take up? With regard to secrecy, I think the trouble in electrical engineering arises from a memory of early days when, if a manufacturer found out what size of wire on the field magnets, together with another size of wire on the armature, would give a pressure of, say, 100 volts, he regarded that result as a secret to be jealously guarded for ever, and went so far in many cases as not to indicate on the name-plate the output of the machine. We have hardly grown out of that spirit yet. I think that a research costs department would be extremely useful. The ordinary works costing department is engaged to the full extent of its time in trying to prevent abnormal costs of ordinary machines, but special circumstances arise in which special groups of costs, or special dissections of costs, are required for experimental or research purposes, and I think it should certainly be considered that the man who deals with these special costs becomes, even if only temporarily, a member of the research staff, so that such work could be done apart from the ordinary routine of works costing. What may appear to be a minor point in the paper is really important. I refer to the author's insistence on the necessity for freedom from too many drawers and lockers. An accumulation of unnecessary material, useful in itself, becomes rubbish if it is stored wrongly, and it is much better to keep all apparatus in a central place as the author suggests. I am greatly interested in the author's suggestions about the psychologist, and I hope that, when he is eventually introduced, the latter will be more tactful and more carefully trained in knowledge of human nature than the average welfare worker of the past.

**Mr. S. A. Stigant** (*communicated*): I was particularly interested in the all too brief reference to the psychological and physiological factors. The author said that it was perhaps anticipatiag events to consider the inclusion of a psychologist in a research organization. I cannot help thinking that this is not his own view but rather that his remark is a concession to British insularity. It is astonishing that engineers, either individually or collectively, should so ignore the oldest science in existence—that of life itself with all its ramifications—as to be in no better position, as many are, than to raise a smile or an eyebrow at the bare mention of psychology. As well as in the choice of suitable men for the many various grades of labour involved, I think that the psychologist should also be consulted in regard to the internal finish of rooms (as regards colours, etc.), particularly in the case of the more highly trained brain workers. I can conceive of nothing having a more stultifying reaction on the worker than being lodged in a laboratory equipped with cold, white, tile-faced tables similar to some of those shown by the author on the screen.

**Mr. A. P. M. Fleming** (*in reply*): I am in cordial agreement with Sir George Hadcock and Mr. Clothier in their views that much important and useful work has been done by industrial firms with modest buildings and equipment, and this explains to a large extent why this country is not so backward as is commonly supposed. Assuming, however, that research work is desirable, nothing is lost, and a great deal is gained, by the formal recognition of research work as one of the functions of an industrial organization, and by the provision of

suitable buildings and equipment. There is undoubtedly an enormous field for co-operative research, and this work may be done to some extent by the research associations now being formed, with the support of the Treasury Fund. All industries would be able to find some processes and materials of such common interest and of such importance as to warrant research being carried out on behalf of the whole industry. Some of these materials, such as coal, are of national importance and will be dealt with direct by the Government. As subjects for co-operative research, one may suggest the art of cutting metals, ferrous and non-ferrous alloys, problems connected with the design of shipping and aeroplanes, and, as Mr. Clothier suggests, large oil switches. Materials and processes which are peculiar to certain works would have to be dealt with by the manufacturer himself, and in practice little difficulty is anticipated in drawing a line of demarcation between the fields of co-operative and private research. It may also be noted that firms finding difficulty in supporting a laboratory may associate either with other firms in the same industry or with firms of a non-competitive character. The value and the output of a laboratory increase much more rapidly than its size, owing to the increased specialization and to the influence of research workers on each other. Hence all efforts at co-operation are advantageous. Manufacturers desiring to keep any processes secret will of course have to do research in their own works. The provision of storage accommodation in the laboratory, mentioned by Dr. Michie, is of great importance, and I advocate the complete removal of all apparatus not immediately required from the laboratory to a store-room.

I am glad to find that Mr. Cook agrees that it is desirable to centralize all experimental work in a separate building. The large buildings would, of course, be erected by firms which have already had considerable research work to carry out, and I am in accord with the suggestion that research work should be allowed to grow. Much of the equipment suggested for the laboratories illustrated in the paper is, of course, primarily for routine testing. It is gratifying to find that the experience of Mr. Cook and Mr. Fawssett leads them to adopt views similar to those expressed in the paper.

With regard to the point raised by Mr. Fawssett about single-story buildings, I have dealt fairly fully with this point in my reply to the discussion before the Institution (see page 190), and would merely add here that the buildings described in the paper are based on the assumption that land is scarce, as is generally the case in industrial areas. Much of the heavy electrical work will require to be carried out in the works on account of its power facilities; other experimental work on a semi-manufacturing scale, such as electrical welding, could be done in the Processes Laboratory. This would leave the sections marked "Electrical Laboratory" free for lighter work.

With regard to the point raised by Mr. Carter, I would suggest that the appropriate middle course to take in connection with testing conductors is to purchase from a trustworthy manufacturer on a purchasing specification, giving details of sizes and limits and of the properties required, to inspect each consignment when it arrives for size, and to take very occasional tests on conductivity. Any trouble arising in the shops which appears to be due to low conductivity should be very carefully investigated. The research organization forms an appropriately impartial department for carrying out this inspection. I agree with the point of view of Mr. Carter regarding costing rather than with that of Mr. Cook, as research costing is entirely special, but it is largely a matter for the individual works to decide.

The recognition of psychological influences mentioned by Mr. Carter and Mr. Stigant will add very considerably in future to industrial efficiency.

## South Midland Centre, at Birmingham, 5 February, 1919.

**Dr. C. C. Garrard**: I have already discussed this paper at London (see page 173), but I should like to add a few remarks with reference to the illustrations of research departments in the paper. I think the window space is too small. The walls of such a building should be practically all windows, which could be obtained with ferro-concrete construction. On page 164 the author states that an intensity of illumination of 3–6 foot-candles is sufficient. This seems to me to be too small. I think $7\frac{1}{2}$ foot-candles should be insisted upon. In this connection an interesting specification has been issued by the Industrial Commission of Wisconsin, and the requirements which this Commission call for are stated in the table on page 390. When new the illumination is specified to be 25 per cent larger. I also do not like the idea of putting the wiring in the ventilating duct as shown in Fig. 25. If a duct is necessary for the wiring it should be a separate one, and this might also contain the piping.

**Mr. W. Wilson**: The need for research in the engineering industry of this country is one of the most urgent, if not the most urgent, at the present time, and the paper is especially welcome on this account. There is one respect in which I should like to see the author's scheme somewhat amplified. On page 154 he mentions the necessity for distinguishing between research work in pure science and industrial research. This distinction is important, but it hardly seems sufficient to lump all the latter research work into the one category, and deal with it in the one department. In particular, the inclusion of routine testing in the research organization is unwise, as the former is an essential part of the works cycle and should be administered under the works manager. But industrial research itself is divisible into what I may call two grades, each of which should be treated separately and be under separate management. In the first place, their functions are distinct; secondly, they require a different class of man to carry out the work; and thirdly, many factories only require the lower grade (using the adjective as representing its position in the scheme), particularly in these days when the products of our

industrial establishments are becoming specialized. To illustrate these distinctions, let the progress of an ordinary factory product be considered. Upon completion in the shop, it is subjected to supervisory inspection by the foreman, and passed on in the regular sequence of things to the test room. Here its fitness for the market is established, by instruments, gauges, and tests generally, and its cycle of operations is completed by its being passed "fit" and delivered to the stores. All this is ordinary works routine, and if progress and improvement are not desired in any respect, nothing further is needed. But as soon as the necessity is recognized for a continual advance in the direction of perfection, then a special department is required, which will be responsible for the developing of new ideas into "manufacturable" commodities, the solution of many of the problems that arise from time to time in the factory, the carrying out of such modifications as may be necessary in the patterns, types, or models of the product, and the making of experiments to determine what new departures and modifications are justified. It is most desirable that none of these functions should be performed by the main shops, which should be concerned only with their own standard work, anything else causing interruptions that are resented by foremen and workmen alike. On the other hand, the head of such a research department, which may be termed the "development" section, must be thoroughly versed in the actual products, as well as in the methods and processes, of the particular shops dealing with them, and in addition with the use and performance of these products in the field. His tests will typically consist of the construction of the actual article, or of those parts essential for his purpose, and the determining of its performance; while he will refer such problems as the properties of materials, tests involving delicate physical apparatus, and the like, to the industrial research department proper. Similarly, the latter will hand over to the development department, or perhaps to several of these working upon different classes of product, a new article which has been brought to a practical, workable shape, but which requires designing and developing, and perhaps simplifying, to fit it for economical and efficient manufacture with the plant available. I consider that the greater stress should be laid upon the development section, in that it has been signally neglected in the past in this country, to the great disadvantage of our industries. Three out of the many instances of British investigators having laid the foundations by discovery and research, of potential industries which were not developed may be mentioned in support of this contention. The vacuum flask was brought to the practical, but not to the manufacturing stage, in this country. Aniline dyes, and the electrolytic lightning arrester, might also have been produced here, but for the lack of the development facilities referred to. I have already mentioned the specialized factory, as requiring more particularly this type of laboratory. An extreme case is afforded by mechanical works, often employing thousands of hands, that are engaged upon quick production of large numbers of standardized components. In the electrical industry we are accustomed to a proper appreciation of technical training, for we simply could not get along without it; but in many of the mechanical factories of this country nearly every member of the staff has risen from the ranks without receiving any theoretical training whatever. In spite of what the war has taught, this lamentable state of things promises to persist for at any rate a considerable time, and to prolong the old method of rule-of-thumb far into the future. A single instance will show how harmful this is. Shops of this description include as one of their most important sections an inspection department, where every article produced is gauged before it is passed for assembly or sale. Now a gauge is a physical and mathematical instrument that demands a mathematical training for its design and application. Yet the head of the inspection department is often a promoted workman who has no knowledge of even the most elementary geometry. The consequent inefficiency is shown in the waste of materials and labour, loss of time, and failures, that have been evident to all connected with such work. A small development depart-

ILLUMINATION INTENSITIES MEASURED AT THE WORK.
(Referred to in Dr. Garrard's remarks, page 389.)

| | Minimum Foot-candles | Foot-candles Recommended |
|---|---|---|
| Roadways and yard thoroughfares | 0·02 | 0·05—0·25 |
| Storage spaces | 0·25 | 0·5—1·0 |
| Stairways, passageways, aisles | 0·25 | 0·75—2·0 |
| Toilets and washrooms | 0·5 | 1·5—3·0 |
| Rough manufacturing, such as rough machining, rough assembling, rough bench work, foundry floor work | 1·25 | 2·0—4·0 |
| Rough manufacturing, involving closer discrimination of detail | 2·0 | 3·0—6·0 |
| Fine manufacturing, such as fine lathe work pattern and tool making, light-coloured textiles | 3·0 | 4·0—8·0 |
| Special cases of fine work, such as watchmaking, engraving, drafting, dark-coloured textiles | 5·0 | 10·0—15·0 |
| Office work, such as accounting, typewriting, etc. | 3·0 | 4·0—8·0 |

ment attached to the factory, that would examine causes of trouble or failure, re-design jigs, gauges, and other tools that were not doing their work correctly, organize a reference or lending library, index the information available in this, act generally in a consulting capacity, and perhaps also afford regular instruction to foremen and others, might easily increase the output by from 30 to 50 per cent. One has only to examine the "scrap" returns of some of our large mechanical works to be able to appreciate this. The illustration which the author showed of "open" benches interested me, as my own practice has been to rely largely upon benches situated round the walls of the laboratory, over sets of drawers and cupboards. I can understand the advantage of the open pattern with regard to cleanliness, but should like to ask the author what other reasons there are for the design. The necessity for avoiding even the slightest vibration is by no means exaggerated. The behaviour of many pieces of apparatus—for example, the melting of a fuse wire—are considerably modified by vibration, and the only way to secure uniform and trustworthy results is to carry out the tests under absolutely still conditions.

**Dr. G. Kapp**: In connection with the subject of the paper one is naturally led to consider what universities and technical colleges can do to promote scientific research directed towards immediate use in industry. They all have laboratories and the men working there do some kind of research. It is quite conceivable, and indeed has happened, that the work done in such a laboratory becomes the starting-point of a development of great utility to a particular industry, but this is not what we at present mean by the term industrial research. Every chemist knows that there is a vast difference between the experiment made in little test-tubes and the industrial process carried out on a large scale. In the same way a research in electrical engineering carried out on a small scale may in many cases be misleading; it is simply a question of power at our disposal. In the laboratory of a university one may have a few hundred kilowatts at disposal, but the industry deals with processes requiring some thousands of kilowatts. I need only mention the development of electric welding as applied in shipbuilding, where for spot welding a current of many thousands of amperes is required at something like 300 to 400 volts. The help a university can give to industry by way of research must be on the whole indirect; it may be by a great discovery which will have to be developed later in one of the research laboratories such as the author has in view, or it may be by training men to work in such laboratories. The former depends upon the lucky chance that a person of exceptional ability happens to work in that laboratory and cannot be depended on with certainty, but the latter we can make a certainty, and it is in this direction that universities can be of real assistance to industry. A previous speaker has said that he finds university graduates not much use in a works laboratory at first; they require some practical experience, which he gives them in the works, and only after such additional training do these men become useful as scientific investigators. The necessity of such practical training has been recognized in Birmingham University. We have made arrangements with some leading electrical engineering firms (the British Westinghouse Company is one of them) to take selected students for 10 weeks during the summer vacation into their works, and I am glad to be able to state that such men, when they come back to us from their vacation courses, not only are better able to profit by our own laboratory work and lecture courses, but have acquired broader views in regard to industrial organization. I am glad to see that the author takes a broad view as regards exchange of information between firms engaged in the same industry. In the United States this is already the rule. If we look at the admirable periodicals issued by the two leading electrical engineering firms in America we shall find that they give freely not only to American competitors, but to all the world, the results of their researches. This is carrying out the principle of co-operation in a liberal spirit. Here, I fear, this principle has not been carried out quite in the same way. We also had co-operation before the war, but mostly of what one might call the purely commercial type, say for the purpose of keeping up selling prices or securing some legislation beneficial to the particular industry. In a scientific sense there was rather rivalry than co-operation. If a firm had spent a considerable amount of money in scientific research and had found out something of real value to its industry, would it have shared this knowledge with a competitor? Probably not. Yet this is what should be done in the national interest. If every firm were to let its competitors know all that is of value in its research it would gain more from the others than it would individually lose. But then there is the question of the small firms who are financially too weak to establish each its own research laboratory. The cost of such a laboratory is very great. I hope the author in his reply will give the figures for cost and maintenance of some of the American laboratories he has shown on the screen. Possibly half a dozen electrical engineering firms in this country could afford the outlay, but what about the hundreds of small firms who, by the very reason that they are too small to employ highly efficient engineers, are more in want of scientific assistance than the great firms? It is here that the principle of co-operation might be employed. Laboratories of adequate size might be established on the principle of a trading company with the firms as shareholders. Any firm who is a member of the company can have its research done by the staff of the laboratory, the cost being charged to the firm ordering the research. The costing should be done on such lines that a profit is made, so that at the end of the year a dividend would be available. The cost to each individual firm would be much less than in the case of each having its own laboratory. This is a sufficiently important matter, but more important still is that by sharing valuable information among all the members of an industry the nation as a whole would benefit.

**Mr. H. V. Kramer**: I hold with the author that the problem of industrial research organization is so vast that even now, with all the available material, it is hardly possible to lay down clean-cut principles. It is therefore perhaps rather premature to discuss details

of buildings and plans of the laboratories. I should like to see more thought given to the great principle which must govern this problem. Personally, I do not see how the erection of large works laboratories would tangibly assist the needs of large mechanical and electrical manufacturing concerns, without some intermediate link being formed between the present works organization and its facilities for design and production and that of the laboratory. I should rather like to see, first of all, attention paid to the erection of a number of experimental workshops, each with a well-equipped test-room or small laboratory specially equipped for the production of specimens of new apparatus developed by any department of a large works, thereby creating a valuable addition to the incomplete system existing in almost every large manufacturing establishment, which is usually not laid out for any experimental work. To this experimental workshop or experimental laboratory a small research library and test-record intelligence department should be connected. Then, and only then, is the departmental manager of a large works in a position to give tangible form to ideas received from the staff of his department, or from suggestions made to him by his clients or salesmen. It would enable him to produce samples quite irrespective and without interference of the regular routine productions for which the machinery of his particular department is laid down. In this way a clean cut would be established between the purely routine productive side of the business and the creative or research side for development. He could supervise and keep in touch with the process of production and the tests made by this experimental workshop in his own test-room or laboratory, which, however, must have nothing to do with routine testing. Thus he and his staff could create complete "manufacturable" articles which his works could copy without alteration and then make in quantities. I am sure that a central laboratory of any of the types shown on the screen or in the paper would not entirely be able to meet the variety of demands in this first and most important aspect, and which is common to all works laid out for quantity productions. I do, however, admit that in addition to the experimental workshops attached to every department, with or without small laboratory facilities, some scientific higher institution, such as a central research laboratory, is essential, and therefore the question arises how the provision of such a purely scientific research laboratory could best be met. In my view it would be a most costly feature if every works were to build its own research laboratory, which has already been made very evident in the discussion. Communal or co-operative laboratories have been mentioned as an alternative, but it is doubtful whether such co-operative research laboratories built for the needs of several works, who would join in the expense involved by the erection and upkeep of such communal laboratories, would be a success owing to trade rivalry, special constructions, or secrecy of ideas. Personally, I should like to see particularly large general laboratories built in almost every county throughout the country, or certainly near every large industrial centre, and State or county supported, so that such research laboratories are not only accessible to the large manufacturers, but to all the smaller works of the district, and at a reasonable fee for the work done for their clients. Such county national physical laboratories would be laid out on a very complete scale, considerably larger than any of the laboratories shown on the screen to-night, and even larger than the National Physical Laboratory at Teddington. Even if it should cost the country 10 million pounds to establish such centres, it would be no doubt one of the most productive national investments. In summing up, I would say that large scientific research laboratories, although very helpful as regards the investigation of scientific principles, or the testing of materials or apparatus, would not be half such a vigorous stimulant as those experimental workshops with their small testing facilities which I have advocated. And, vice versa, I admit that such workshops should be aided by some scientific research institution, although I doubt whether more than a very few firms would invest approximately £100,000 in building their own research laboratories, with an upkeep cost of from 1 to 2 per cent on the turnover of their business. Such money, in my view, would be much better spent in first equipping efficient experimental workshops, grouped perhaps for one or more similar departments, and in paying a contribution to the establishment of county research laboratories, or in paying fees which would become reasonable enough if there were more than one national physical laboratory in the country.

**Mr. J. M. Walshe:** The research laboratories and organization described by the author are expensive, and it may be useful to point out that much valuable research work can be done in the testing departments provided by manufacturers for ordinary routine tests. Manufacturers of steam engines and turbines who have a well-equipped test-house with ample boiler capacity are in a position to experiment on a larger scale than would be possible in any ordinary research laboratory. The great improvement in the thermal efficiencies of steam turbines in recent years is largely due to such private investigation, and an efficient testing staff is a very paying proposition. The results of ordinary routine tests if accurately made and recorded will often supply the answer to new problems. For example, a good deal of attention is being given at the present time to the use of exhaust steam for heating and process work in factories, and in planning such schemes it is necessary to estimate closely the thermal efficiency of engines working against high back pressure. Records taken some years ago of the steam pressures and temperatures in the intermediate receivers of compound and triple-expansion engines have supplied the necessary data for this, and costly experiments have been unnecessary. Much time and expense can sometimes be saved by searching the technical Press before starting an investigation, and one often finds in published articles information bearing on the subject to be investigated, which, if not always exactly what is wanted, at least saves one from going over ground already covered.

**Mr. A. Krause:** I should like to ask the author what method of remuneration he would suggest for inventions in the scheme outlined by him, having

regard to the radical change suggested for industrial development.

**Mr. A. Ryan**: In the case of a large firm engaged in a multiplicity of manufactures covering electrical, mechanical, civil, aeronautical engineering, textiles, rubber works, and shipbuilding, it would appear that there are three courses to choose from, viz. (1) a central laboratory for the whole firm, (2) a laboratory for each department, (3) to subscribe to a communal laboratory in each branch in conjunction with the other firms. I should be pleased to know which of these courses the author would recommend or whether he would prefer some alternative. With regard to the question of national laboratories, judging from experience one would be inclined to think that the results of researches carried out were chiefly for the benefit of Government Technical Departments, as although the information is generally published, the firms interested generally receive the information a year or so after the results are known. It would be beneficial if the firms could have immediately it is available the information likely to assist them.

**Mr. C. V. Peake**: I should like to emphasize the importance which I consider attaches to the adequate provision of suitable workshops, to be exclusively devoted to the manufacture of experimental machines or other apparatus. My experience is that only with the greatest difficulty, and by dint of constant and oft-repeated pressure on those responsible in the shops, can experimental machines be built and made ready for the test bed. This is perhaps natural, as the point of view uppermost in the mind of the works manager is to maintain the maximum possible output of saleable machines. Although the carrying out of large castings and many other operations will of necessity take place in the ordinary workshops, yet the assembly and general direction of all experimental work should be conducted in a workshop attached to, and controlled by, the development department. These remarks apply equally, of course, to any alterations which are required after the first tests have been completed.

**Mr. G. H. Ayres** (*communicated*): I am decidedly of the opinion that in all cases the routine testing and the research work should be under the control of one director. The functions of the various sections of the organization, as outlined by the author, seem in places rather to overlap the purposes of other departments. For instance, sections (8) and (9) should be covered largely by the jig and tool design or efficiency department, whilst other sections should be covered by the works engineer or plant equipment staff, provided always that these latter are given proper facilities for experimental work and access to the records of progress of manufacturing processes: in other words, if the works engineer is allowed to carry out his duties on a scientific basis. In regard to research upon the reclamation of waste and by-products, I am inclined to think that few manufacturing firms would find it policy to undertake this work themselves; it would appear to be better to consult existing concerns who lay themselves out for this class of work, the very origin, existence, and prosperity of these concerns depending upon their willingness and capacity to tackle new problems. The plans of the buildings in the paper are open to criticism, an imposing frontage apparently being the main object, whereas if the research laboratory is to be centrally situated with respect to the whole works a square block with exits on each side would be found advantageous. To have the offices, library, and record rooms in the centre, with the sectional test-rooms and laboratories on the outer portion, suggests itself as being desirable.

**Mr. A. P. M. Fleming** (*in reply*): I am glad to note that Dr. Garrard considers that the illumination figures given on page 164 should be increased. The tendency is certainly in favour of increasing intensities. With regard to natural illumination, very large window areas have been made possible by ferro-concrete construction and in this case probably windows are cheaper than brick filling. Such large window areas, however, are not an unmixed blessing: they involve higher maintenance cost for cleaning, and rooms are subject to greater temperature variations. Under some circumstances it is possible to have too much light inside a building. In the buildings illustrated, the window area has been designed very carefully, consideration having been given to the width of the building and the amount of space occupied by the floors. The height of each window has also been made as large as possible in comparison with the width.

Mr. Wilson recognizes the necessity for segregation of all experimental and development work in a factory, and this is the main thesis of the paper. While a broad distinction exists between the two kinds of research required, the co-ordination necessary between them is such that, for any given works, the two departments should be under one control, and in my reply to the discussion before the Institution (page 189) further reasons are advanced for including routine testing in the early stages of development. I am of the opinion that the work to which Mr. Wilson refers as development work will comprise the major portion of the work which the works research department will be called upon to carry out.

Apart from greater ease in keeping the laboratory clean, the open type of bench has advantages over the ordinary type in the fact that laboratory workers are under no temptation to hoard rubbish and inflammable material in cupboards and drawers. There is not the same need for storage accommodation in the bench as exists in a school laboratory; apparatus not required should be kept in a special store-room and properly marked. In general it is very desirable that there should be as little obstruction as possible in those portions of the laboratory which for purposes of supervision may be considered as units.

Dr. Kapp has outlined the case for industrial research very lucidly, and I am in cordial agreement with his views. All men entering the engineering industry should receive preliminary practical experience of a varied character, and it is to university laboratories that we must look both for the training of men for the industry, not only in research work but also in other branches, and for much of the research in pure science which must always be the foundation for industrial development.

With reference to the methods of minimizing the

expense of industrial research to individual firms, two methods are available. One method, which has hitherto progressed little, is the formation of co-operative research associations, while the other follows from the policy of industrial amalgamation which is taking place on a considerable scale, which will facilitate the maintenance of a research laboratory to meet the requirements of the members of a group of firms. A third method, mentioned by Dr. Kapp, that research should be carried on by a company having interested works as shareholders, has some features in common with both these methods. It has one disadvantage. Concerns sufficiently closely allied in their work to be competitive would not care to join in the control of a separate research company, while those firms which are not competitive would find much less advantage in so doing.

The two large American firms referred to by Dr. Kapp—the General Electric Company and the Westinghouse Company—spend £75,000 to £100,000 per annum in maintaining their laboratories. The Eastman Kodak Company similarly spends £30,000 per annum, and the American Rolling Mill Company £10,000. The annual maintenance cost of the laboratory of the Pennsylvania Railroad Company is £100,000 per annum, although this is largely spent in routine testing.

In reply to Mr. Kramer I would say that the buildings outlined in the paper are intended to some extent to act as experimental workshops. For some processes and products a factory type of building will perhaps be more desirable, some particulars of which are given in reply to Mr. Paterson on page 190.

Few works of course will be able to carry out pure science research and for this we must look to State laboratories, such as the National Physical Laboratory, and university laboratories, together with the laboratories of private investigators.

The fact that Great Britain was able during the war to adapt herself to war needs, showing thereby unexpected resources and elasticity, is largely due to the work done by routine testing laboratories, as pointed out by Mr. Walshe. These laboratories have frequently carried out work beyond the function for which they were equipped and staffed, and may fairly be expected in many cases to make a nucleus for a research organization.

With regard to the point raised by Mr. Krause, I would say that my experience with respect to invention, either from the engineering staff or from suggestions by workmen, has not been promising. It seldom happens that a man makes a discovery concerning his work which is not improved by, or which has not in part been due to, some colleague. In research work this principle of co-operative working should be stimulated as much as possible, and I am in favour of increasing the salaries rather than of paying bonuses or royalties for inventions.

In view of the tendency mentioned above towards industrial amalgamation, the point raised by Mr. Ryan is of extreme importance. Considering the enormous advantages to be gained by centralizing research work, I am in favour of the provision of one large research laboratory for all the works concerned, together with a local laboratory at each works for the purpose of dealing with immediate requirements and with the control of materials, working in co-ordination with the central laboratory. At the central laboratory the work to be carried out would be actual research work, and with the individual works laboratories would be associated a building for the experimental development of new processes and products peculiar to the works. The tendency towards centralization in research inevitably follows similar tendencies with regard to purchasing, manufacturing, and selling, particularly in view of the importance of the group being kept fully informed with regard to developments from a central intelligence department. It is imperative that industrial research work needed should be done by the industries themselves, although the national laboratories may be expected to carry out a great deal of pure science work.

I fully endorse the matter raised by Mr. Peake, and the workshops in the research department should be equipped to do a wide range of work at short notice.

In reply to Mr. Ayres, the research department only overlaps the other departments mentioned in so far as it is able by its resources and staff to assist them by co-operative working.

## North-Western Centre, at Manchester, 11 February, 1919.

**Professor E. W. Marchant**: After seeing the author's lantern slides it has struck me very forcibly that nearly all the large-scale research work at the present time seems to be in America. It is very much to be deplored that in this kind of work we have not gone ahead more quickly in this country, but possibly we have done more than the author has told us. If manufacturers do not take it up soon on a much larger scale, we shall ultimately feel the effects industrially in a very serious way. In a written communication to the London discussion (page 186) I dealt with some of the many subjects mentioned in the paper, but I should like to say a few more words. First, as regards libraries, I am sure that anybody who has had anything to do with research work must feel in agreement with the author on that matter. The library is really at the root of the whole business of research, and is essential if the laboratory is not to repeat work which has been done before. The author has also described a method of eliminating vibration in which the table has indiarubber feet resting on the top of two piers. I have tried that method and it works extremely well. It is best not to get solid rubber feet; one should have a more or less flexible rubber body such as a tennis ball. The latter are much the best for rapid vibration, but it may be necessary to adopt other types of anti-vibration devices when the vibration is very severe.

**Mr. B. Welbourn**: Professor Marchant has said that he is not sure we are so far behind America in research work as we are supposed to be. It

is a national habit with us to depreciate our own progress. This was illustrated very forcibly a few weeks ago when a colonial telegraph and telephone engineer, who had been quite recently round the small works' laboratories of this country and also the more elaborate ones of the States, told me that we have nothing whatever to learn in this country from the United States in regard to telegraphs and telephones. During the last four or five years I have thought a great deal about the necessity for having a central library in this country which should act as a co-ordinator of the whole of the published scientific literature of the world and make it available for engineers and research people and scientists generally. I might even suggest that it would be a worthy war memorial to establish such an institution, and this might be done as a joint effort by all the engineering institutions and scientific societies. On a small scale it already exists in every research department, but something more comprehensive seems to be required—a sort of well-indexed world-wide reference library in this country to which all scientific workers can refer, with the certain knowledge that they can quickly find out what has been published anywhere, on any particular subject. Translations into English should be made available whenever the governing body of the library thought foreign work of sufficient importance, and it might be possible to publish cheap English editions of foreign scientific books. The training of men by the universities is a fundamentally important question. I have been wondering where the staffs were to come from, and I was very glad to hear Professor Marchant say that the universities are laying themselves out to train men—especially, as I understand it, for the staffing of research organizations. The research worker is born, he is not made. I think the amount of really pure research work done in the works organizations will be very small; it will be left largely to the existing research worker, the pure scientist, who is a *rara avis*. The word "research" has been more abused of late than any other word in the British language, and personally, if I had a proposition of this kind to put before a board of directors I would not mention the word "research." In many works, it would be much more correct to describe the department as the "testing, experimental and development department." This would permit of the carrying out of the necessary industrial investigation work. The works' conditions are not suitable for pure research work, and this will probably continue to be done by the few people in the world who have those rare qualities of mind which can wrest Nature's secrets from her.

**Professor M. Walker**: No one can look at those pictures of the American Institutions without seeing that we have a great deal to learn and a great deal to do; and it is very welcome to see that a move is being made on these lines by at least one big firm, and that other firms are preparing to follow. The researches that the author speaks of certainly provide for such things as testing materials and so on, and that is very necessary in a big electrical engineering works; but I believe we shall not make much progress in the future unless we have also an organization of what I call the greater research, that is to say, research on big machines, which must be done in the factory itself and backed up by a board of directors prepared to spend a good deal of money in investigating what are the most useful lines to go upon. If we go back 40 years, we find that the machines then made were not what electrical manufacturers now produce; such things as induction motors, rotor converters, a.c. railway motors, etc., were not even thought of. Now I venture to say that in the next 50 years there will be changes in electrical engineering quite as great as those which have happened in the last 40 years, and there will be entirely new types of machines performing entirely new functions for industrial purposes. If this country is to be in the forefront of manufacture, it will have to do something in the way of developing the new machines, and this can only be done by organized methods. Every large manufacturing concern ought to have a department whose business it is to see what kind of plant is likely to be required by manufacturers for all sorts of purposes. The electrical engineer must look into every kind of business where money is being made—paper making or whatever it may be—and see if there is anything that he can do better than it was done before. It is his business to find out what is wanted; it is the business of somebody else to find the money—to spend a thousand pounds if necessary in building a machine (which possibly may work imperfectly or not at all), and to continue experimenting until he gets something that does the work. We must have a bold policy. If this country is to stand forward as a progressive country, manufacturers must be prepared to expend some of their profits in experimenting on those lines. Mr. Welbourn has said that research workers are born, not made. I agree that they are born—we are all born—but I most emphatically say that they are made. It ought to be possible to give everyone who has any spark of genius a suitable training so that he can be made into a research worker. What do I mean by the spark of genius? I will not deny that there are individuals born who have some extraordinary inborn gift; but my reading of the lives of such men as Newton, Faraday, and Kelvin is that, although they had very fine faculties, the real reason why such men succeeded is that they had the right sort of moral fibre. No one can read the life of Faraday without being struck by the fact that it was Faraday's integrity that carried him through his work. Integrity is a thing that almost anyone may have, and I do not say that in itself it would be sufficient; but I do say that it is a *sine qua non*. If we can cultivate in our students the habit of mind of going on honestly and steadfastly, grappling with the difficulties that present themselves, not shelving or evading them, we shall have accomplished a great deal. I am not satisfied with our schools and our universities in that respect. English spelling is one of the rocks on which the lives of thousands of would-be scientists are wrecked. A system of illogicalities is absolutely crushed down into the child's mind. We want to have in this Empire a great modern university. One can picture, somewhere in the Pennine range, a beautiful campus surrounded by trees and hills, where the student can go out in a fine atmosphere. If we

bring him to a town like Manchester, he comes out into miserable fog for a third of his time. That is not the atmosphere in which to make a great scientist. There has been talk of raising national memorials. Let us have a great modern university for the British Empire, with fine surroundings, and then we shall have a chance of training men to take part in this great work which the author has organized.

**Mr. R. W. Bailey**: The question of the supply of staff is undoubtedly the most important one that has to be tackled in regard to research organization. The suggestion that the works apprentices should pass through the sections of the research work other than routine testing is excellent; it gives an opportunity to select men whose educational record has been dealt with previously. All engineering teachers know that only somewhere about 30 per cent of their students are good at experimental work. Perhaps that figure is rather high. If, therefore, the works organization were put in possession of the technical college records of young men entering apprenticeship it would be of great assistance in the selection of men to pass through different sections of the research organization. I am strongly of the opinion that a period in the workshop is essential before the post-graduate research training is given. Very few young men know what their bent is until they have been in the works. Also the atmosphere of the works gives them balance. Routine testing and research work should be taken together; there is so much that is common to the two, and the problems that crop up during routine testing generally require research for their investigation, and improvements and advances can thereby be made. We are all agreed as to the importance of the intelligence section. There is needed a central organization which will spread information over the country; and the work of collecting data can be done very largely at one place. The expense of an intelligence department falls most heavily upon small firms which need research just as much as the larger firms, and they would be helped considerably by such a central organization. The curves shown in Figs. 1 and 2 indicate the rate of expansion that may be expected. When it is borne in mind that the rate of progress will normally be something like proportional to the knowledge accumulated, the rapid expansion exhibited by the curves is not surprising.

**Mr. J. S. Peck**: We see pictures of these immense buildings and their splendid equipment as they exist in America, and we realize at once that a very large amount of money is involved, first, in building and equipping, secondly, in running expenses. Do these expensive laboratories pay, or are they merely fads which are supported by large manufacturing firms? I think we all believe that they will pay in the end, but are they paying now? We must carry on research work, but it is a difficult matter to show that these very elaborate buildings and equipments are necessary. The average board of directors is not specially interested in research, as such; what they want is to make their undertakings pay, and until we convince them that there is money to be made through research they are not likely to build and equip such buildings.

**Mr. J. P. Bedson**: I am sorry to say that in this country the financial element or the capital element of a business is too much under the control of the capitalist, and the intelligent expansion of a business cannot always be secured. To some directors the most important item is the dividend; it is all the same to them whether it is made out of a high-class article or a low-class article. I do not like to mention Germany, but it is as well to take a few leaves out of the German book, and they have set us splendid examples in the laying out of works and the co-ordination of capital and the technical side of the business undertaking. This has been carried farther in Germany than in any other country. On a board of directors there is the commercial side and the technical side. The technical side say to the commercial side: "We want certain things doing, and it is for you to find the money," and the money is found. It is not on the technical side alone that education is needed; the financial side needs it as much. I was rather surprised by some remarks of Professor Walker. It is very nice to hear him speak of a university built in a pure atmosphere, and he was perfectly right in saying that moral tone and integrity are very vital points. That applies to the training of any man, but particularly so when the object is to make a good scientific man. The forecast, however, of what we shall be doing 50 years hence is a little in the air. In 1892 I visited works in Belgium. The firm had set out to make small motors, and in 1892 it undertook the building of large low-speed dynamos without having any other experience. The machine was of 400 or 500 horse-power, 80 revs. a minute, which had never been contemplated in this country. That showed the quality of the technical education given in Belgium. At Liège also the electrical education was very excellent. Greater powers are being used to-day, but the principles are the same. Where there were boilers working at 20 lb. pressure there are now boilers working at 200 lb. pressure; it is only a matter of increasing the strength. Professor Walker must not forget that the records of Manchester, despite its gloomy atmosphere, include the names of Dr. Joule, John Dalton, De Quincy, Sir Joseph Whitworth, Sir Henry Roscoe, and one man who did a great deal in the early days of electricity, and is still alive, Dr. Henry Wilde.

**Mr. A. Saxon**: There are many problems awaiting solution so far as the engineering world is concerned. The author has specialized in this subject and therefore speaks with authority and experience. He has made out a good case backed up by definite and well-considered plans which are sufficiently flexible to meet most industrial requirements. I think all who have carefully considered the question agree that research work will pay. We may not get precisely what is sought in the investigation, but we do get something which is worth the trouble and expense. In view of the shorter working week (which seems likely to be still further shortened) scientific research must come to the aid of industry by the development of new processes, labour-saving appliances, and the selection of the most suitable materials, so that an economical output may be obtained.

**Principal J. C. Maxwell Garnett**: I was exceedingly interested in Professor Walker's remarks on integrity of purpose, and I heartily concur in his opinion that there is nothing more important in education than the development of that quality. I also agree with him in thinking that it can be produced, that it can be trained. There seems to be indubitable evidence that certain mental qualities are innate and are not greatly altered by any educational process, but there seems to be also absolutely uncontrovertible evidence that other mental qualities are profoundly modified in the course of education. One of them, I believe, is the power to concentrate attention, and another is this integrity of purpose which, extremely developed, has marked some of the greatest men that have lived. Professor Walker has referred to the training of researchers: there is room here for very close co-operation between the engineering industry and the universities and colleges that are concerned with the training of engineers for research and for management. As the author points out in the paper, training in research work is to be accomplished partly in the works themselves, but also in a very great part in college laboratories, under professors and other people who have devoted a large part of their own lives to work of that nature. Anything that increases this co-operation will increase the number of competent industrial research workers; and I feel quite sure that many courses of training would be improved by being conducted partly in the college workshop and laboratories and partly in the works. If a young man has had a considerable amount of works training before entering the college, or is of sufficiently brilliant promise to justify the expectation that he will become a research worker, it is rather an open question whether immediately after taking his degree he should go on with his training in research work or go into industry for a time and come back two or three years later for training in research work. The principal difficulty in the way of the latter course has hitherto been financial; but the Government Research Department is now prepared to make grants of £200 or £300 a year (and sometimes more) to a man who has to sacrifice an income exceeding that amount in order to go back to college to be trained in research work before returning to the works. To be efficient, a works research department must be large. If a particular factory is not a great one it cannot afford to maintain an adequate research organization; after a certain point has been reached the output of a research laboratory increases very rapidly with the number of men employed in it. How are the smaller firms to secure the results that should follow the development of works research organizations? One way is by co-operating in forming a large industrial research institute or several research institutes. In such a Research Institute there may be rooms set apart on the plan of the Mellon Institute, where confidential investigations can be carried out by individual firms who are not able to establish their own research departments. Another way is by making use of college laboratories on the Mellon Institute lines. A great deal has been done in that direction, and a great deal more ought to be done to make effective use of college laboratories for industrial research. I should like to add this. By bringing industrial research into the college and university we are helping to train individual researchers; but if we do not entrust to these institutions work of that kind we shall not be able to get as well-trained researchers as will otherwise be the case. One aspect of the work is connected not so much with the machines and the processes as with the men who are employed in the industry. I think that research upon matters connected with the human side of industry and other problems of industrial administration will increase continuously, and become recognized as most important during the next 50 years.

**Mr. J. H. Lester**: I think a little modification ought to be made in the author's definition of pure research as being devoted to the enlargement of the boundaries of knowledge. There is very little in the way of research which may not have some practical application and be necessary for building up knowledge for specific purposes. It is therefore very important to give a very large place to pure research even in the industrial organization, and I am sorry to find that many of these large American institutes are more like testing-houses. There are fine laboratories, and excellent analytical work is done in them, but that is a different thing from research. It is true that the two things go together to some extent, but when we introduce routine work into the research laboratory of a great institution we are limiting the research work that it is possible to do there. Someone comes along who wants a particular problem to be solved, and research is laid aside for the moment. Each must have its proper place. The same equipment may be used for both purposes, but individuals whose first duty it is to look after research should, if they do any routine testing at all, keep it in the second place. The matter of libraries has been mentioned. It must be a very big undertaking that can set up an adequate library for technical research; it is a better plan for firms to have their laboratories within easy reach of suitable libraries. The research laboratory of the firm with which I am connected is in very close touch indeed with libraries; it is an important part of our equipment. I quite admit that we want much better technical libraries in Manchester. In planning any research organization of course the first thing is to get a first-rate man. I do not see how a man can go into an industry where but little research has been done, or where he has himself had little experience of organizing research, and at once plan out a big research scheme. He must begin with small things and progress gradually. The question of salaries is very important. I doubt whether a purely research organization can be based on an average of £200. It is extremely difficult to get men who have the necessary brains and powers of observation, and when found they must be paid an adequate amount. Of all kinds of industrial research it may be questioned whether electrical research is the most involved, or that there is a wider field for research in the electrical industry than there is, for example, in the textile industry. One speaker has asked what progress is being made in the establishment of research laboratories. Unfortunately the progress is extremely slow, but there

is a movement going on and some firms have already established their research organizations. It is very difficult to measure the progress in the early years; it is necessarily slow. We cannot build up a thorough organization in a very short time. We do not know what our troubles will be, but we find them out as we go along.

**Mr. C. E. Stromeyer:** The establishments which have been described this evening seem to be very large for the works to which they are supplying information, and I have wondered whether they are intended to pick out the best of things—like an expert who looks through a heap of mud and picks out a diamond here and there—or whether they are intended to be of the nature of cinder-sifters which deal with anything that comes into the works, letting the bulk of the matter fall through, perhaps even a diamond here and there, and keeping only a few good things. If these institutions are cinder-sifters it means that they must be on a very large scale, a very large number of experiments having to be made for comparatively small results. I believe that sort of research work is very necessary in chemical works, because their research work is exploration. The chief value of the enormous laboratories of the German chemical works is the enormous number of failures of which they keep the records. These failures are not to be found in public libraries. For engineering in general the correct principle is the other one—that of picking out the good things. The inventor has not been mentioned this evening, but he should be part and parcel of these institutions. For the purpose of picking out the best things in engineering practice it is essential to have researchers. Men are wanted who have the power of seeing the essential points and going for them, but I am afraid there are not many of them. An eminent researcher told me only to-day how very few men there were who could really go ahead with a thing. He had many excellent men who worked and did most careful experiments, but they did not seem to get inspirations. He had had only two or three men who, when they got hold of a subject, gripped it with that stiffness of fibre which has been mentioned so often this evening and in doing so obtained wonderful results. It was not advantageous to hamper such men with the management of large establishments, and it was not a good policy to make them the subordinates of inferiors. Such men should rather have the use of the laboratory than be made part and parcel of it.

**Mr. S. Chadwick:** The question has been raised by one or two speakers as to whether these research institutions really pay. In many cases the assistance they give to the manufacturing departments more than offsets the cost of the research work, and in one or two American research laboratories it has been found that the latter have paid for themselves by the sale of by-products produced in the laboratory itself whilst investigations have been in progress, quite apart from any grant which the firm may set aside for research purposes. The author mentions the lack of technically-trained men. The reason seems to lie in the fact that only a few people are able to proceed to institutions where technical training can be obtained. If we had a system of Government grants for those who are prepared, but cannot afford, to go to such institutions, there would, no doubt, have been a much larger supply of technically-trained men available to-day.

**Mr. J. F. Shipley:** I appreciate very much the necessity for a good library in the intelligence department. Owing to the lack of such libraries in Liverpool my firm have had to set up one for ourselves, and it has been so successful that in Peru and Chile we have done the same thing on a smaller scale. We have used these libraries not so much on research work as to help the engineers at their work. I am told that at the Sulzer works most of the research work is not done in the works itself but in the laboratory of the Polytechnic at Zurich. The laboratory there is a vast establishment, and Sulzers keep it supplied with all their machines, large and small. The students of the Polytechnic and the engineers of Sulzers co-operate; secrecy does not seem to be observed except in extraordinary cases, and the results of practically every investigation are published monthly in a book which costs 10d. I have had the opportunity of going through some of the research departments of the A.E.G. in Germany. They were decentralized, one being in each separate factory department. The German firms paid considerable attention to research, not from the point of view of science alone, but also with regard to the appearance and finish of the goods. Persons so employed were paid high salaries. About 1912 the A.E.G. decided that all its products which had to be enjoyed—such as ventilators for use in houses, lamp fittings, advertisements, arc lamps, small motors of every description—must be submitted to an art director. I think the director was Professor Behrens, of the Munich Art College. They paid him, I believe, £1,000 a year merely to come to the works two or three times a week at convenient times. Every manager of a manufacturing department had to submit designs to him for approval. In the publications and material of the A.E.G. evidence of his work will be found.

**Mr. J. D. Paton:** In regard to the question asked by Mr. Peck whether any of these institutions had been known to pay, I should like to advise him that one of the most successful has been proven out in Cardiff, namely, the Mining Board and School of Mines at Treforest. The foundation of this originated in a little room in Wigan College about 10 years ago. It was introduced in detail with a system of education, preparation, co-ordination of technical institutions, laboratories and the entire industrial facilities of the mining industry to act along the same lines which were now desired. It was introduced to the University at Manchester, to the Mining Institution of this territory, and while acknowledged an ideal, was refused. The leading spirit was George Knox, late of Wigan Mining College and now director of the Mining Board at the School of Mines in South Wales, which receives 1/10d. from nearly 90 per cent of the coalfields of South Wales. As a matter of profit on return, there are cases in the mines of South Wales where the co-ordination of the Board and the owners has resulted in the saving of many thousands of pounds, and the evidence of its apprecia-

tion and value is to be found in the enormous grants which are being allocated and now willingly subscribed by the principals of the Board for new laboratories and other research work. I must again plead for definite action on the same basis for the author's programme. Unless one has a driving power through which one can apply a moral good to an involuntary community until they, through experience, become voluntary applicants of the advantages of the system, one is wasting time and energy. In the same way as 1/10d. has been contributed by the coal-owners of South Wales to the administration of the Board, so must our electrical industries contribute to their research investigations, and I would suggest that a levy be made on excess profits to apply a fund for the development of this institution instead of providing pensions by way of controllers, who have little true knowledge of the needs of the industry, for indolent labour.

**Mr. J. G. Pearce**: Some speakers have pointed out that this country is not so backward as is commonly supposed, and that a large amount of original work has been carried on by industrial concerns without any publicity. This has been done in many cases, often under severe handicaps, in the ordinary works laboratories provided for routine testing, and it forms a further argument for allowing such a laboratory to become the nucleus of a research organization. It is erroneous to suppose that a research organization not making specific provision for pure science research necessarily carries out its industrial research in an empirical and therefore unscientific manner. There is only one research method, which is the same for both pure and applied research, requiring in both cases men of high scientific training. It is unfair to draw a sharp contrast between the research worker in pure science, actuated solely by motives of broadening the field of knowledge, and the industrial research worker, moved only by sordid commercial considerations. The only difference between the two, as the author has pointed out, is that the one knows exactly the end he is to achieve, and the other does not. The difference is one of aim, not one of motive or method. Which type of work is selected depends on temperament, training, opportunity, or economic considerations, and no special brand of research is exclusively confined to one institution, whether it be a works, university or national laboratory. Many so-called pure science workers are really engaged in industrial research. Any attempt to make industrial research the Cinderella will only react unfavourably on pure science research, and it is gratifying to find that industrial research is considered by those competent to judge and to exercise an impartial judgment to be more exacting to the worker and more difficult than pure science research. Another unfortunate tendency is that which would invest all pure science workers with an artistic temperament which demands protection from the grosser forms of discipline and restraint, and which renders them oblivious to time and space, unconcerned about ordinary human relationships and very difficult to fit into an organization in which co-operative working is a most important feature. While it is undoubted that many brilliant minds are erratic or abnormal, the bulk of research workers, even in pure science, are probably not so characterized, at any rate to the extent implied. If this is the case, there is comparatively little scope for such men in industry. The question of the intelligence department and library has been referred to by several speakers. At first sight, the solution of the problem appears to be a large central library and bureau in London, supported or carried on by the Government. Mature consideration, however, indicates the weakness of such a proposal. A point is arrived at beyond which centralization defeats its own end, as is illustrated by the British Museum. Further, the provinces require facilities. Every works and laboratory should have a bureau which can search for information and catalogue references. Co-ordination of existing State, municipal and other libraries, and concerted action on the part of those already interested in special subjects, whose work in many cases is overlapping, would be a more satisfactory solution.

**Mr. H. D. Symons** (*communicated*): On page 154 the author recommends that the majority of firms when commencing research work will find it expedient to combine the necessary routine testing with research work, and I heartily endorse this, as in my experience the combination of "industrial" and "scientific" research under one head and in one department is most beneficial. In the first place, the educational influence on each other and on the works as a whole is more effective; secondly, by this means research is more economical from all points of view, but particularly in guiding the scientific research into the most effective channels; in my experience, when scientific research is influenced and surrounded by industrial conditions it is more effective; thirdly, this research is often of great value in the investigation of troubles outlined in heading (9) in the second column on page 154; and lastly, it would enable the research department to weather periods of bad trade, during which there is a temptation on the part of the executive management to reduce expenditure by curtailing the activities of the research department. Referring to the paragraph headed "Technical Processes" on page 155, whilst I agree with the author that in some processes development requires the employment of plant on a semi-manufacturing scale in the research department to carry through the whole of the manufacturing experimental work, so that the entire information can be turned over to the works in such form that it can at once be placed on a commercial manufacturing scale, the number of cases where this can be done will not be great; in by far the greater number of cases I would recommend that this development could be carried on more advantageously in the works itself. The educational value of such a development is most beneficial to the works; the elimination of all experimental initiative in the works is cramping to the responsible officials and workers, tending to lead to reduction of interest and initiative, which is undesirable. Further, valuable suggestions are often forthcoming from those who undertake any new process when placed on a commercial manufacturing basis. I note the author makes a special point of the scope for a works research department in utilization of by-products, and this

cannot be too strongly emphasized. Regarding psychological and physiological research, there is a great necessity for interest in work of this nature, particularly in view of the reduction in working hours, which is being so largely adopted. Properly handled, this research can have most far-reaching effects on the efficiency of a works. On the question of an intelligence and information section, I think the author hardly lays sufficient stress on the absolute necessity for such a section in any research department; it is impossible for the work of the department to be effective without it. Indeed, parsimony in this section is a great mistake. I particularly endorse the practice suggested by the author of a standard method of preparing reports and the necessity for recording the very smallest and apparently insignificant details. It is a very small point really, and one which is frequently ignored, but when given proper attention it increases the efficiency of the department enormously. The author does not give his views as to how the upkeep of such a department should be provided for, and this is frequently arranged for by the allocation of a certain sum per annum to cover the work of the department. While this is advantageous from the executive management's point of view, it is not in the best interests of the work the department has to do that its upkeep should be so arranged; indeed it is general experience that where the department is properly handled the resulting economies which it effects entirely cover any expense that it may be to the firm. With regard to the question of the design of the buildings, the author has dealt with this subject quite fully; there is only one point I should like to suggest—it is certainly desirable that any research laboratory should be fitted with double windows. The question of equipment has been dealt with on very broad and general lines, and it should be as flexible as possible. In every instance I would recommend the installation of instruments and detail apparatus of the best possible kind, as it is impossible to do anything like good work unless the best facilities are provided. The apparatus can always be adequately protected by suitable store accommodation, and I consider some good means of store-keeping is essential for economical working. I entirely agree with the author's remarks with regard to the staff; remuneration should be adequate, and the department should feel the benefit by compensation in the form of bonus on the economies effected as a result of their work or in the establishment of new branches of industry. By this means the department is brought face to face with hard facts, which are a great incentive to making research work effective. The author has summed this matter up very fully in the second paragraph of his "Conclusions," in which he calls attention to the fact that as a result of research the difference between manufacturing cost and selling price can often result in a profit in a much more effective manner than by trade combinations or other means of protection.

**Mr. A. P. M. Fleming** (*in reply*): Professor Marchant and Mr. Welbourn have referred to the position of this country in relation to the United States. I am of the opinion that we are not so far behind as is commonly supposed, but the publicity methods adopted in America to make people acquainted with what is being done may well be imitated to a greater extent on this side. Any work carried on by a manufacturing concern has a publicity value quite apart from its intrinsic value.

Mr. Welbourn and other speakers have referred to the question of the library. Attempts which have been made to found a central library and index to the world's literature, of which the well-known Institute at Brussels is an excellent example, have not fulfilled the expectations of their founders. In part, the reason is that the people who collect and index the information, not being in touch with the industries, are not in a position to evaluate it, and thus it is difficult for them to provide an information service; their very centralization also makes it difficult for inquirers to visit them every time information is required, or to wait for an inquiry to be dealt with by post. I am strongly in favour of each works or university, or any institution requiring an information service, setting up a small organization for the systematic collection and indexing of matter likely to be useful. These information bureaux may ultimately find sufficient common interests to make a central organization useful.

I am in cordial agreement with Professor Walker's remarks regarding the need for a bold policy and for looking well ahead; that should be the function of a research department. I also believe that training is of great importance in connection with research workers, although inherent mental equipment determines to what extent this training may be successfully carried.

I am interested to learn from Mr. Bailey that about 30 per cent of students of engineering are good at experimental work, for dexterity in experiment is a valuable quality in all research workers.

In reply to Mr. Peck's query, I do not think that anybody who considers the history of some of the great American or German laboratories can deny that they not only have been profitable, but have placed the companies with which they are associated in the very first rank and enabled them to remain there. Every progressive works must make provision for systematic expansion, and those companies which are not sufficiently enterprising to do this will find that their business will either remain stationary or decline.

I agree with Mr. Bedson that those who have financial control of firms require to appreciate the influence of science in modern industry. That this is not already the case is largely due to the neglect of science in modern education.

Mr. Saxon refers to the necessity for research assisting in improving production to meet the demands for shortened hours and higher wages. It is sometimes thought that research is mainly of value in developing new processes, but existing processes offer a field of investigation so full of possibilities that in manufacturing industries prices may ultimately fall lower than ever before.

Principal Garnett has emphasized the importance of co-operation between works and technical colleges, and a closer co-operation between the two will have

very favourable reactions on industrial work, largely in connection with the supply to industry of better trained men. Such co-operation should be strongly encouraged.

I am in accord with Mr. Lester that every research laboratory should have a library close to it. Firms actually in the city may be able to make use of city libraries, provided they are sufficiently specialized for the purpose. The average of £200 given for salaries is merely a figure utilized for purposes of illustration. It is an average which includes the wages of office boys, janitors, and similar members of the organization in addition to technical workers.

Mr. Stromeyer has referred to the inventor. It is not likely that what may be termed full-time inventors will be attached to research departments, for the reason that very few men display the inventive faculty continuously in any works. Men who have ideas for the improvement of processes or products should be given facilities for developing their ideas fully on a workable scale in the research department.

In reply to Mr. Paton, the electrical industry in common with other members of the community already contributes to the cost of research through the provision of one million pounds by the Treasury, but I do not think a direct levy is desirable or possible.

I am glad to find Mr. Symons confirming the recommendations given in this paper. I would suggest that the segregation of experimental work in the research department will not eliminate experimental initiative in the works, since the research department will act in co-operation with other engineers in the works. Consequently their ideas would receive more attention and far greater opportunities of trial, and in special cases, as mentioned above, engineers may work out their ideas in the research department itself.

## Western Centre, at Bristol, 31 March, 1919.

**Mr. H. I. Rogers :** It is undoubtedly a fact that, as the author states, conditions have altered very materially owing to the war, inasmuch as very much higher wages are now demanded. This assuredly means scientific organization and research work, which, although it has hitherto been carried out quietly on a considerable scale in this country, must be very greatly extended if we are to play our part in foreign trade. Prior to the war it was possible to compete with Germany and America, but I do not think this is possible to-day under the old *laissez faire* conditions, so high are wages and consequently materials. It is therefore absolutely essential that research work should be carried out to a greater extent than in the past. The Coal Inquiry may be taken in conjunction with this paper. Now that shorter hours have come into vogue it is essential that scientific management should be brought into play in the colliery, and it is to the engineer we must look for the attainment of reduced costs together with increased output. Industrially we have passed through a bloodless revolution, but I think we need have no fear regarding the future. As a nation we have shown what can be done in the war, and this especially applies to our engineers, and I feel certain we shall be able to sweep away all difficulties.

**Professor D. Robertson :** There is one point on page 156 which bears on a subject I have emphasized before, and it is one worth repeating. I refer to the supply of trained men. For the future welfare of our industries, it is essential that a reasonable proportion of the best brains of our population should be drafted into research work. But we shall not get them unless we offer inducements equal to those of other careers ; in other words, we must greatly advance present salaries and offer much better prospects than are now open to a youth taking up this branch of work. Otherwise the men we want will continue to be diverted into less useful (from the national point of view) but more lucrative professions. In his recent paper,* the late Mr. Constantine proposed a " Director-in-Chief " of research at £1,000 per annum. Should this ever materialize, it will, I suppose, form the plum of the research branch of our profession. How many posts like this, or bigger financially, are open to the legal profession ? Is there any need to ask further why so much of our best brainstuff goes into legal careers ? The author's remarks about co-operation between the universities and local manufacturers are most apposite. Such co-operation must often lead to progress which would be possible in no other way. Many problems are unsolved because the men who meet them are too busy or have not the scientific knowledge to tackle them, whereas the university research worker who may have both never hears of them. Instead, he has often to invent his problems, sometimes only to find after their solution that they are not real problems in the works at all. Here, at Bristol, we should be only too glad if the local firms would bring us problems in which we might assist them, but unfortunately we are not surrounded by numerous large engineering works as in Manchester.

**Mr. W. A. Chamen :** I agree that a great deal more research work has been done in this country than is commonly supposed, but that it has been kept secret or hidden. The information which the author has given us is extremely interesting and will doubtless prove very useful. The fact that research is a means of saving waste is one which certainly should be impressed upon the mind of everyone concerned. We are perhaps rather apt to think of research in the first instance as the making of new scientific discoveries and the finding out of scientific facts and principles which will enable us to take new departures and to make new or further uses of the forces of Nature. But the author has shown us that research really covers a very great deal more than that, and that it is indeed necessary in many ordinary matters for the purpose of finding ways of saving waste, both in cost and in time, in the matter of many ordinary manufactures. The author's remarks with regard to genius are extremely interesting, and it is very important to note that, while the brilliant

* " Co-ordination of Research in Works and Laboratories."

genius has his place, such a vast amount of most valuable work falls to be done by others whose gifts are of quite a different nature, namely, careful, plodding, conscientious perseverance, and steady continuity of work. A detailed point of interest in the various suggestions for research buildings is that in every case the designer provides the director's office with three doors—usually one opening from the corridor, or through an ante-room, another into the general office, and the third into the library or conference room—seeming to indicate that even directors of research require protection such as other more ordinary people have found convenient.

**Mr. A. Ellis:** This paper deals with a subject with which we all agree. In the first place there is no industry so capable of the development of research work as the electrical industry. We must keep up our position after having come satisfactorily through this terrible war, as competition is going to be very severe. I gather from the paper that research work is more developed in other countries, particularly America, than it is in this country, in consequence of the fact that is has been taken up by large firms for their own particular requirements. One significant case out of many referred to is the magnificent laboratory provided out of Carnegie funds, and it occurs to me that, if we are to compete successfully with other countries, research work is worthy of Government financial assistance in order that all classes capable of being trained can have the necessary opportunity. I do not think there is a lack of men who are capable of being technically trained. I am glad the author agrees that the "sandwich" system of training is satisfactory. With regard to buildings, an interesting feature is the provision of ducts, and if this had only been generally adopted in many ways, how many of the difficulties with which we now have to contend would have been eliminated by the provision of large ducts through our principal streets. Gas, telephone, traction, water and other mains could have been laid, and extensions provided for without the necessity of having to take up the roadways again. Unfortunately we usually discover these things too late. I am glad the author has mentioned the cost of buildings. In Cardiff we have erected a new Technical College, a portion of which it is intended to set aside for research work. We have a magnificent building, in the erection of which the character of the district and the other public buildings in the immediate vicinity had to be taken into account, with the result that some £55,000 has had to be spent on the provision of the building itself. In regard to equipment, a long discussion took place when it was suggested that a sum of £5,000 would be required for this purpose. I have no doubt there will be a much longer discussion when the provision of properly trained men for the training of the youths of the country comes forward. From the point of view of research work alone it would have been better if the greater amount of the total money spent had been spent on the provision of equipment and the payment of suitable salaries to those who will be responsible for the administration instead of upon the building itself. The second paragraph of the author's conclusions is a very interesting point and one we must keep in view. We suffer to-day as a result of the formation of rings. If these firms, as a result of research, could reduce the cost of production, they would be benefiting not only themselves but the community at large.

**Mr. A. C. MacWhirter:** One vital point to my mind is the necessity for co-operative research, which would mean the saving of not only time and money but possible disappointment of the individual. The lack of trained men is, I think, entirely due to the miserable remuneration offered for this important branch of work, and unless we are prepared to offer our young men an attractive remuneration we cannot expect to get the highly trained men required. I think we shall all agree that the British scientist is second to none, but in the past his discoveries and inventions were never made use of at home, and as a result many key industries found their way into foreign countries. I trust that that short-sighted policy will never recur. I was particularly interested in the photograph of the buildings of the General Electric Company of Schenectady and should like to ask the author if the whole of the buildings shown are used for research work. I happened to see this building going up from the foundations. It was built not for laboratories but as general offices with dining-rooms in the basement, general offices on several floors, and draughting department on the top floor. I presume some of these have now been turned into laboratories. One interesting point in connection with this building was that the foundations were laid in very frosty weather, the cement and mortar being mixed with hot water and after use covered with straw and matting. This structure was erected in record time, being started in January 1901 and completed in June of the same year.

**Mr. W. Nairn:** A point of special interest to us is the class of organization which would be most suitable for Bristol requirements. In this town practically all the trades of the country are represented, with the result that we have a very large number of comparatively small firms and a very few large. The large ones of course can provide for themselves under classification No. (1) and the problem is to cater for the smaller ones. Considering the smallest size of laboratory outlined by the author we find the estimated cost of maintenance to be £8,700, a figure which is beyond even a combination of similar trades, and it seems to me that the author's classification No. (2) is the one most suitable for this area. I should like to suggest that as one of the principal objects of the proposed research work is the conservation of the nation's resources of raw materials, it should be made compulsory for works to have their plant and processes inspected and checked for efficiency, say, once a year, and that such inspection should be carried out by the laboratory engineers engaged on routine work. The recent inspections which have been carried out at the instigation of the Coal Controller have revealed many cases of inefficiency, and there is no doubt such inspections would effect considerable savings to the works and at a comparatively small annual charge. Such an arrangement would also bring in a steady revenue for carrying on the work of the laboratory and would

also ensure that the laboratory engineers were kept in close touch with the industries of the country, and a steady stream of suggestions for research work would be forthcoming. There is nothing very startling about compulsory inspection; steam raisers have been used to it for years, and the inspection of boiler plant by specialists has proved a great relief to many works managers. The architectural details form a valuable portion of the paper, and as electrical engineers we shall all appreciate Fig. 29 showing a 6 ft. 9 in. × 4 ft. duct for cables and wires. I am sure we all hope that the development of these laboratories will not be long delayed.

**Mr. A. Nichols Moore:** This is eminently a paper for specialists, and it seems to me impossible for the uninitiated to grasp the importance of the subject or at least the detailed requirements of research laboratories, but when the author in his conclusions ventures into the domain of industrial economics we may possibly find subject matter for criticism. It is to be observed that not a great deal has been said either by the author or by those taking part in the discussion on the subject of national laboratories or national research. In his conclusion he says: "In many cases it is the impoverished industry which stands in the greatest need of research. Similarly, the smaller concern, though it may not be able to afford expensive research facilities, can make considerable use of those afforded by universities, national institutions and private or commerical laboratories. Then, again, the wealthy firm or prosperous industry can maintain an unassailable position through improving by research its methods of production, this being ultimately the only effective method of securing monopoly." There we have in a nutshell a great deal to think about and to criticize, and it is chiefly for these reasons that I think the introduction of State-controlled laboratories would more materially benefit the smaller industries, and especially so than if research works were privately owned. We should certainly be most optimistic if we assumed that private firms are going to continue to be as patriotic in these matters now that war is over as they were during the war in regard to disclosing the results of independent research. Private research would not, I am afraid, necessarily mean that the purchaser is going to reap that benefit for which he otherwise might be entitled to look. We all know that the control of industry is gradually drifting into the hands of a few gigantic financial combines, the ultimate result being possibly to freeze out the smaller manufacturers who, after all, in the aggregate form one of the chief supports of industry in this country. It is for these reasons that I should like to see the development of laboratories on a national basis and nationally owned so that all could derive equal benefits from the research work carried out therein. Moreover, if we have competing firms pursuing the same object of research we are in a great measure wasting brains and valuable time, for could we not have the same problems pursued in one laboratory either State owned or at least State controlled and a particular research carried out by one staff therein instead of independently by several staffs in the research laboratories of competing firms.

**Mr. A. L. Stanton:** I think it unfortunate that the author has felt it necessary to go out of this country in order to furnish us with planning details such as I hold must be necessarily governed by the demands of the particular works with which they may be associated. Personal experience leads me to state that the conditions in America differ greatly, both materially and psychologically, from those which prevail here, and it is deemed a matter of regret that no information regarding existing conditions in this country has been given and no reference made to the valuable work carried out by, for example, the National Physical Laboratory and Messrs. Hadfields, Ltd., respectively representative, I believe, of high-grade State-controlled and of privately-owned research work developments. It is furthermore thought that a far wider meaning is attached to the word "research" than is usually associated with it. Referring, for example, to the enumerated functions of a research organization, it is not easy to accept the idea that such an organization should be vested with the control of matters grouped under headings numbered (3), (4), (5), (9), (10), and (11), and I venture to think such inclusion embraces elements entirely outside the scope of "research" as commonly interpreted. Works managers, engineers, production superintendents, view-room chiefs, and other similar executive officials directly or indirectly responsible for production, cannot, it is thought, be placed (as the author's grouping would seem to infer) subordinate to a research department without impairing the efficiency of production operations. Perhaps this point can be rendered more clearly. Without any desire to be misinterpreted, it is not felt amiss to mention that there exists a "commerical aspect" in industries, which the majority of purely technical sections here have a reputation for disregarding, and it is by no means difficult to find evidence indicating how important sections in many large industrial works suffer from a short-sighted policy of starvation, owing to the excessive expenditures incurred under the heading of research and experimental costs. Education of the right kind is the need, and systems of technical training which neglect the commerical aspect of industries are faulty. If the true value of team work and co-operation between research and production departments is to be realized to the highest degree from a national point of view, it can only come about by educational methods which demonstrate its utility, along lines free from departmental antagonisms, mistrust, and prejudice. Another point not quite clear to me is the reference made to routine testing as associated with a research department. In many large works routine testing is carried out as an incidental of production operations, and it is presumed the author does not overlook or overlap this. It would also appear that the cost figures quoted by the author for originating and running a research department are prohibitive, unless either associated with large industrial enterprises or combines which permit of an advantageous centralization of facilities desired, or equipped as State-controlled research centres situated in localities where their utility is justified. No one can dispute the value of research work when conducted along proper lines,

but the great need is one of developing the latent intelligence which the population of our own country undoubtedly contains. Incentive to take up research work will help this forward, and if to this can be added a greater freedom from obstructive legislative measures, combined with a breaking down of the prevalent beliefs in some quarters that a monopoly of intelligence can be maintained, then and then only will a step forward towards recognizing our real place in the work of the world be demonstrated.

**Mr. F. H. Downie:** The subject of industrial research is indeed a very important one, and sufficient attention has not been paid to it in the past, though the position is changing for the better. The author points out that in many cases routine testing and research work must be carried out together from the point of view of expediency. As he remarks, this method has the advantages that the capital cost of building and equipment is reduced. As a rule, however, a successful member of a research staff is usually possessed of a peculiar type of temperament, which must be allowed for. Frequently when engaged on a major research, the mere fact of routine testing being carried out in the same room will annoy and worry him. This is detrimental to the quality of the work done and the speed at which it is carried out. Provision should always be made for special rooms in which research work may be done. In connection with the routine testing one point is often neglected, namely, the provision of proper and representative samples of the material under test. The sampler should be a member of the routine testing staff and responsible to the director of the laboratory. Standard methods should be adopted for the taking of the sample. A useful addition to the library section of the research department is a section on statistics. This section should collect and tabulate the market prices of all raw materials used or likely to be used in the works as well as the quantities available. Many new processes in the past which were the result of the expenditure of much time and money in research have been commercial failures, since either the raw material used has been available in insufficient quantity or the price has been so high that the process was not sufficiently remunerative. Chemical industry is perhaps more affected by these considerations than any other. The author rightly lays much stress on consultations between the director and his staff. It would also be very beneficial if conferences were held between the research staff and the works manufacturing staff. In some industries the director of the research department might be consulted with advantage by the buying staff in connection with the purchase of raw materials. The selling staff as well should consult the director of research when customers put forward inquiries for new types of plant or products. A useful addition to the equipment of a routine testing department is the provision of standard samples, whereby the accuracy of each tester can be checked by the director at intervals. This will prevent the tester from becoming careless, which can quite easily arise through the tester being bored with the constant repetition of the same type of work. A convenient addition to each research laboratory is a dangerous operations room where experiments which might cause a fire, or where explosions might result, could be carried out with safety to the operator and the main laboratory building. In planning any scheme, however, it is important to remember that money must not be stinted, either in salaries or equipment, once the main lines of the scheme have been decided.

**Mr. F. Tremain:** So much needs to be done in this country to make political, educational, and industrial administrators appreciate the need for technical education, research, and standardization, that I would suggest the reprinting of this valuable paper, independent of the *Journal*, for propaganda purposes, with an abstract of the discussion. I am inclined to think that the compilation of cost statistics and their graphic representation might well be made a branch of a research organization. It seems to be of vital importance that the effect, for instance, of wages and rate of output on competitive prices should constantly be kept under review and made widely known amongst workpeople. The more closely research work is associated with industry the more valuable it will be. I am therefore glad to see the "sandwich" system mentioned in this connection. In technical education the principle of students spending part of their time in works and part at college is bound to bring into the college a greater atmosphere of reality, but might not our professors and technical teaching staff also with advantage withdraw more frequently from the cloistered seclusion of their colleges to the noisy industrial world. Mathematical deductions would be none the less valuable if worked out in closer relation to the actual limits of measurement necessary and possible in practice; lectures and demonstrations would have a closer relation to current industrial needs and practice; and research workers themselves would benefit by an intimate knowledge of the productive plant they are chiefly concerned with.

**Mr. A. P. M. Fleming** (*in reply*): Mr. Rogers has raised the important question of the possibilities of research in enabling industry to bear the burden of the shorter hours and higher wages now universally demanded, and yet to compete successfully with America and Germany. There can be no doubt that manufacturing costs may be lowered substantially by systematic investigation and by manufacture on scientific lines, and further investigation in many fields will enable new industries to be established. It is this constructive value of industrial investigation which renders it necessary for the rewards to be commensurate with the importance of the work carried out, and when it is considered that such work involves a higher and more specialized training than any other form of professional employment, it will be readily conceded that the remuneration of investigators both in industrial and in pure science research must be extremely high if the ablest men are to be attracted and retained. The constructive character of the work is an inspiration in itself to capable men, and the tendency to offset this by the payment of low salaries must be deprecated. This point is specially referred to by Professor Robertson. In view of the importance of making the fullest use of existing technical institutions and universities it is

to be hoped that manufacturers, especially those without organized research departments, will freely refer difficulties experienced in practice to them.

It is most important that the point raised by Mr. Chamen should be generally realized. Research in industry can be used to improve existing materials and processes in addition to developing new ones through the application of new scientific discoveries. It means making the fullest use of the discoveries of our great scientific leaders.

I am in cordial agreement with Mr. Ellis that there is no lack of men capable of profiting from technical training; in fact the proportion of men in the population of Great Britain who could appropriately be trained technically for our industries is probably greater than in any other country. As has been pointed out in the paper, the most important factor in connection with the provision of research work is the staff and equipment, and buildings come last. It is therefore regrettable to find that there is a tendency to spend money on buildings and to starve institutions with respect to equipment and staff.

Mr. MacWhirter and Mr. Nairn raise the question of co-operative research, and there are undoubtedly numbers of small firms who would be unable to establish facilities for research in addition to routine testing, but who would be willing to join together for the purpose of conducting a laboratory. The Research Associations of the Department of Scientific and Industrial Research illustrate the principle of co-operative research.

An interesting laboratory was commenced some months ago in Birmingham, when a number of firms engaged in the brass trade formed a central laboratory for the purpose of carrying out routine tests and of investigating difficulties. The firms concerned have no other connection than the one through the laboratory, and payment is made roughly in proportion to the amount of work they require to be done. The laboratory is governed by a Board on which each firm concerned is represented. As far as I remember, the whole of the floors of the General Electric Company's laboratory at Schenectady are not yet occupied, but at least five complete floors are devoted to research work.

With reference to the compulsory inspection of plant and processes mentioned by Mr. Nairn, I am of the opinion that it is preferable that manufacturers should feel the pressure for improvement coming through competition rather than that a compulsory system of inspection should be imposed, although the proposal is by no means impracticable.

The remarks of Mr. Nichols Moore deserve special attention. I am of the opinion that it is desirable in the main to leave pure science research to the universities and national laboratories, and for industrial laboratories to undertake industrial research. While a certain amount of industrial research may be done in national laboratories and universities, the bulk of it can only be done by those who are in close and direct touch with the industry itself. Manufacturers, particularly large manufacturers, would not care to submit their development work to laboratories outside their own works. Even if the research is paid for by the manufacturer there is a danger of leakage of information, and most manufacturers prefer to control their own work themselves. About 50 industries have been considering the formation of Research Associations and some five or six have actually been formed, including the photographic, scientific instrument, cotton, linen, woollen and non-ferrous industries. The National Physical Laboratory will undertake much of the work of these Associations since it is the official laboratory of the Department of Scientific and Industrial Research, and the Associations will also make use of university and other existing laboratories. These laboratories should be able fully to provide for the requirements of small firms such as Mr. Moore has in view. I am fully in agreement with Mr. Moore that there is great scope for co-ordination in industrial research. Pure scientific research cannot be organized in the same way and does not offer the same scope, because overlapping and duplication are frequently desirable in such work. The co-ordination of industrial research, however, is being effected partly by the formation of research associations, as already indicated, and partly through the prevailing tendency in industry towards amalgamation, which will result in groups of firms maintaining one research laboratory instead of several. A single central laboratory, whether privately or nationally owned, would be so much out of touch with all the varied industries in the country that it could not effectively carry on industrial research.

In reply to Mr. Stanton, the function of a works research department undoubtedly embraces a much wider scope than is usually associated with the term "research" in its academic aspect. In so far, however, as the research department would be associated with productive departments in a works organization, it must be carefully borne in mind that the relationship is one of co-operation. There is no intention of subordinating productive departments to the research department. The research department offers guidance, advice, and experimental facilities where it is able to do so. It is my experience that the section of a works in this country which is generally starved is that devoted to research and development, and it is this which placed us in the precarious pre-war position in which we found ourselves. The research department itself of course would, in common with other works departments, entirely subordinate itself to the commercial aspect; that is, it would aim at assisting in rapid and cheap production. In the discussion before the Institution I have outlined further reasons, in addition to those given in the paper, for placing the research and routine testing departments under one control.

In reply to Mr. Downie, it will be clear from the design of many of the laboratories illustrated in the paper, that separate provision is made in small rooms for research workers. I cordially agree with Mr. Downie regarding the importance of statistics in estimating the commercial basis of new processes and products. As indicated above, it is considered of the utmost importance that there should be constant co-operation and discussion between the members of the research department and the works staff. Given

a good staff, it is uneconomical to a degree to stint them with regard to apparatus or equipment, or to inconvenience them by unsuitable surroundings.

Mr. Tremain grasps very clearly the conception of research in its industrial aspect as distinguished from its academic aspect, and this distinction is of very great importance. One of the main objects of the paper is to draw attention to the possibility of research as a new economic weapon. While I do not think that the sandwich system of education necessarily brings educational institutions more closely into touch with practice than is the case with other methods, I am fully in agreement with Mr. Tremain that both education and industry would gain by a more intimate contact.

# ELECTRIC POWER SUPPLY DURING THE GREAT WAR.

By Arnold B. Gridley and Arnold H. Human.

(*Paper received* 28 *May*, 1919.)

**1.** *Object of record.*—No record of the great efforts exerted in all branches of engineering, both by employers and by employees, during the Great War would be complete unless it included some reference to the share of the burden borne by the electrical engineers of Great Britain. This paper is intended to show, necessarily inadequately, what has been done, primarily by the public service undertakings, both Municipal and Company, and by the electrical manufacturing firms, and secondarily to explain the War policy of some of the Government Departments associated with the direction of the industry.

**2.** *Munitions production accelerated by public electric supply service.*—The War had not been many weeks in progress before it became evident that it would involve a struggle between the great nations engaged in it for supremacy in the application of engineering science to every branch of warfare, and, as the combat prolonged, the call upon the brains and inventive genius of engineers became ever more insistent. Extensions of existing engineering factories and workshops and the construction of new factories, many of them National, were rapidly planned and carried out. The directing heads of many firms were called in to advise Government Departments, in particular the Ministry of Munitions, and to take responsible posts, often without remuneration, in creating, organizing, and accelerating the manufacture of every kind of war munition. The equipment of many new factories and the extension or adaptation of existing workshops were carried out at amazing speed. This was facilitated by the fact that so many of the public service electrical undertakings were able to deal with additional load by running all their generating plant, including reserve, until such time as the stations could be extended. In numerous cases valuable time was thus saved, and munitions of war made available for both Armies and Fleets months earlier than would otherwise have been possible. Electrical equipments in factories could be installed much more rapidly than power-producing plant could be manufactured and erected, and although electric supply undertakings took risks in running all their generating plant, it was felt by the Government that this was a legitimate war risk, even if the supply of current for domestic purposes was thereby jeopardized.

**3.** *Necessity for electrical control.*—As time went on the demand for increased production and changed types of war munitions grew at an always accelerating rate, and it was thereafter a never-ending struggle to extend the public generating stations in industrial areas rapidly enough to meet the insistent demand for larger supplies of electric power. Shortage of labour and materials made it essential that the output from the works of electrical manufacturing firms should be brought under Government control, so as to secure that only such orders should be proceeded with as were necessary to meet urgent National needs. Similarly, the extensions of electric power stations and mains systems were restricted to schemes authorized by the issue of Priority Certificates after applications had been investigated and approved by the Electric Power Supply Department of the Ministry of Munitions.

**4.** *Establishment and objects of control.*—On the formation of the Ministry in the spring of 1915, it was not at first appreciated how large and important a part was to be taken by electrical engineers in munitions production, and no Department was included in the organization to deal with the supply of electric power. In a few months, however, it was found that power supply affected almost every war manufacture, and a Department was created to deal with all electrical engineering questions. The main objects kept in view were to facilitate the supply of power by the public service undertakings to munition factories, to help such undertakings as were called upon to extend their generating stations to obtain new plant as quickly as possible, and to regulate and control the order of manufacture by makers of electrical machinery.

## PART I.

### Electric Power Supply Development.

**5.** *Expansion at Sheffield and Coventry.*—Particulars of the great electrical development in the industrial centres of the country will be interesting. In some areas as, for example, the great steel and armament centre of Sheffield, and the busy machine-tool and motor-engine building district of Coventry, both Corporations were overwhelmed with pressing demands for large supplies of power. Large extensions of generating-plant capacity were rushed forward and proceeded day and night. Great credit is due to the Electrical Engineers of the Sheffield and Coventry Corporations and their staffs for the way in which they rapidly carried through, in circumstances of unprecedented difficulty, large additions to their power houses and mains. While it may be thought invidious to mention these two electrical undertakings in particular, it must be remembered that their war expansion has been phenomenal. The following figures are indicative of this :—

| | | Sheffield | Coventry |
|---|---|---|---|
| Units sold | 1914 | 26,500,000 | 17,000,000 |
| ,, | 1918 | 177,500,000 | 53,000,000 |

**6.** Sheffield's output in 1918 was about 6½ times, and that of Coventry 3 times, the 1914 production. It is also a fact to be noted that, in addition to the Sheffield Corporation's generating stations, some of the large armament firms have their own power houses, and the aggregate output of these private generating plants almost exactly equalled the Corporation's output. In other words, the 1918 production of electricity in Sheffield alone was about 350,000,000 units. No other industrial area—Sheffield covers about 38 square miles only—can show so large a consumption of electricity per square mile. As soon as possible the Corporation will doubtless induce the owners of private generating stations to cease producing their own current and to take their requirements from the Municipality, in view of the resultant economies and advantages which would follow.

**7.** *Great development of electrical furnaces.*—The great feature of Sheffield's electrical expansion was the installation by the steel manufacturers of electric furnaces. For various reasons — which it is not within the purposes of this record to discuss — the electric furnace prior to the War had made little headway in this country as compared with Germany and the United States. There are now, however, about 117 furnaces installed, or being erected, and of these no less than 74 are in the County of Yorkshire, by far the larger number in Sheffield itself. There can be no doubt that the makers of high-grade steels were faced with war problems which could only be solved by the extensive use of electric furnaces.

**8.** *Expansion at Rotherham.*—Another undertaking which has shown remarkable expansion during the War is that of the Rotherham Corporation. In 1914, this Corporation's generating-plant capacity aggregated only 5,180 kw. Since then they have found it necessary to install a further 65,350 kw. The power demand inside the Corporation boundaries grew enormously, one consumer alone, namely Messrs. Steel Peech and Tozer, requiring 10,000 kw. for their new steel works. After careful consideration it was found desirable that the Corporation should erect a new power house, and a station designed to contain two 12,500-kw. sets and one 25,000-kw. set was rapidly planned and pushed forward and is now approaching completion. When this station is in operation, it will contain the largest machines so far constructed and installed in any generating station in Great Britain, although there are of course other power stations of greater aggregate capacity, made up, however, of a larger number of smaller machines.

**9.** In order to ensure that the efficient plant which the Rotherham Corporation will possess is used to the best advantage of the surrounding district, arrangements have been made for linking up this station with the Blackburn Meadows generating station of the Sheffield Corporation, so that 10,000 kw. can be transmitted either way.

**10.** The plant capacity of Rotherham before the end of this year will be nearly 13 times the 1914 plant capacity.

**11.** *Other large plant extensions.*—Of other undertakings which have carried out or ordered extensive plant additions during the War, the following are the more important :—

| | (Installed or Ordered) kw. |
|---|---|
| Newcastle-upon-Tyne Electric Supply Co., Ltd., and associated companies | 114,200 |
| Glasgow Corporation | 99,500 |
| Sheffield Corporation | 73,000 |
| Birmingham Corporation | 51,650 |
| Manchester Corporation | 46,450 |
| Clyde Valley Electrical Power Company | 37,500 |
| Leeds Corporation | 33,660 |
| Bradford Corporation | 27,450 |
| Mersey Power Co., Ltd. | 24,500 |
| North Metropolitan Electric Power Supply Co. | 21,068 |

**12.** A complete list of all power station extensions arranged for during the War is given in the Schedule at the end of this record.

**13.** *Expansion of many other electrical undertakings' outputs.*—Other parts of the country in which abnormal expansion took place were as follows :—

Increase in Units Sold in 1918 as Compared with 1914.

| | Increase |
|---|---|
| Newcastle-upon-Tyne Electric Supply Co. Ltd., and associated power companies | 203,547,122 |
| Glasgow Corporation | 90,250,000 |
| Clyde Valley Electrical Power Co. | 89,942,505 |
| Birmingham Corporation | 77,962,851 |
| Manchester Corporation | 74,953,007 |
| Shropshire, Worcestershire, and Staffordshire Electric Power Co. | 50,549,772 |
| Leeds Corporation | 34,800,732 |
| Liverpool Corporation | 27,967,346 |
| Bradford Corporation | 27,129,229 |

| | Increase |
|---|---|
| North Metropolitan Electric Power Supply Co. | 25,921,117 |
| Wolverhampton Corporation | 25,806,186 |
| Rotherham Corporation | 20,219,945 |
| Greenock Corporation | 18,749,536 |
| Yorkshire Electric Power Co. | 18,673,871 |
| Midland Electric Corporation for Power Distribution, Ltd. | 16,982,773 |
| South Metropolitan Electric Light & Power Co., Ltd. | 16,833,862 |
| Mersey Power Co., Ltd. | 15,582,000 |
| Stockport Corporation | 14,892,745 |
| Lancashire Electric Power Co. | 13,266,574 |
| Derby Corporation | 12,000,000 |
| Bristol Corporation | 10,702,527 |
| South Wales Electrical Power Distribution Co. | 10,083,812 |
| County of London Electric Supply Co., Ltd. | 9,983,586 |
| Bolton Corporation | 9,910,284 |
| Battersea Borough Council | 9,718,584 |
| Hackney Borough Council | 9,472,697 |
| Halifax Corporation | 9,333,120 |
| Rochdale Corporation | 9,176,788 |
| Huddersfield Corporation | 9,084,355 |
| Fulham Borough Council Electricity and Destructor Works | 8,046,892 |
| Hull Corporation | 8,026,719 |
| Metropolitan Electric Supply Co., Ltd. | 7,861,101 |
| Oldham Corporation | 7,783,199 |
| Hammersmith Borough Council | 7,730,644 |
| Stepney Borough Council | 7,569,593 |
| Aberdeen Corporation | 7,558,946 |

**14.** *Other electrical developments.*—Apart from the great development in the use of electric furnaces, the next most interesting expansion was probably that of the use of electrically-driven compressors in shipyards. Shortly after Lord Pirrie became Controller-General of Merchant Shipbuilding at the Admiralty, he decided that the installation of electrically-operated compressors was the keynote of more rapid shipbuilding production, and a large programme of compressor installations was put in hand in various shipbuilding centres, some 80 compressors being ordered, totalling in all approximately 33,000 horse-power.

**15.** The use of electricity for welding ships' plates is also now being experimented with, and its wider adoption at an early date is anticipated.

**16.** In a less important degree, the use of electricity for cooking purposes has largely extended during the War, particularly in connection with the establishment of National Kitchens. In the Newcastle district, where electric cooking has been actively pushed, there is a cooking-load arranged for totalling about 4,000 kw.

**17.** During the early months of 1918 attention was drawn by a leading English electrical manufacturing concern to an improved form of electric regenerative dynamometer gear which could be used in the testing of aeroplane engines. It was known that for direct-current systems it was quite possible to utilize a regenerative dynamo, but no satisfactory alternating-current machine had been devised up to then.

**18.** The design of this firm was carefully investigated and it seemed evident that it could with advantage be used in the test-room of aeroplane works for regenerative operation. An effort was made with certain leading aeroplane engine makers and with the Aircraft Supply Department of the Ministry to have these sets introduced. As shown later the saving, based on a very conservative estimate, would be extraordinarily high and would redeem the cost of the electrical equipment in a few years.

**19.** Unfortunately it was found that some 6 months at least would elapse before these sets could be placed on the market, and the aeroplane makers at that time were rather in doubt as to the future policy of the Air Board as to the size of engines. Further, one of the leading electric supply undertakings refused to sanction these regenerative sets being connected to their system. Negotiations were being conducted just before the date of the Armistice, and ceased on the Armistice being signed.

**20.** Further work should undoubtedly be done both by the electrical manufacturers and the internal-combustion engine makers to develop and introduce an electrical regenerator for all test-rooms. In fact one would go so far as to say that the time should come when nothing but a regenerative form of dynamometer should be allowed in the test-room of any engine maker.

**21.** The following table is a hypothetical case of an aeroplane engine works turning out per week some 60 engines of 250 i.h.p. each.

| | |
|---|---|
| 1. Number of engines tested per week | 60 |
| 2. Indicated h.p. of each engine | 250 |
| 3. Average duration of each full-load brake test | 2·5 hours |
| 4. Number of regenerative dynamometers | 10 |
| 5. Total capital cost of dynamometers | £15,000 |

On the assumption that the overall efficiency of the dynamometer is 50 per cent :—

Total units produced per week

$$= 60 \times 250 \times 0{\cdot}5 \times 2{\cdot}5 \times 0{\cdot}746$$

$$= \text{say, } 14{,}000.$$

On the basis of 1d. per unit this represents £58 per week as the value of the current obtainable, or, say, £2,900 per year.

**22.** *Growth of electric power supply.*—The following data give some idea of the great expansion in the generating plant capacity and output of the public electric supply undertakings during the War. (Power stations supplying railways or tramways only, and private plants, are not included) :—

(1) 103 Municipal and 33 Company-owned power stations were extended or built.

(2) The plant capacity of 327 municipal undertakings increased from 705,000 kw. installed at June 1914 to 1,490,000 kw. installed, or on order, at 31st October, 1918. Similarly, some 230 company-owned power stations expanded from 430,000 kw. to 788,000 kw.

(3) The additional generating-plant capacity installed, or ordered, during the War therefore aggregated 1,143,000 kw., which is almost exactly equal to the total plant capacity existing when the War broke out.

(4) The capital outlay involved on these extensions, with additions to mains and substations, was approximately £23,000,000.

(5) Before the War the average size of generating unit installed was 522 kw., and the largest unit in operation was of 8,000 kw. capacity. The average size of unit on order at 31st October, 1918, was 7,044 kw., and units of 25,000 kw. and 30,000 kw. were being built.

(6) The units sold during the year ended 30th June, 1914, were 2,100 millions. For the year ended 31st December, 1917, they were 3,520 millions. The figures for 1918 are not yet available in the aggregate, but it can be assumed that the output for that year was nearly double that of 1914.

(7) The coal consumption per unit sold in 1914 was 4·1 lb. In spite of the very inferior fuel used in 1918 in comparison with 1914, the coal consumption in 1918 fell to 3·75 lb. This was, no doubt, due to larger and more efficient plant being brought into use, and to the improved load factor at which many power stations operated during the War.

In 1918 the coal consumption in municipal stations was 4·17 lb. per unit, and in company stations 3·17 lb. The latter figure is to some extent accounted for, no doubt, by the greater areas, more diversified load, and better load factor of some of the large power companies.

(8) In 1918, the load factor of all the municipal stations combined was 28 per cent, and of all the company stations 33 per cent. The load factor of individual stations varied widely.

(9) The units sold per kilowatt of plant installed were 1,658 by the municipalities and 1,882 by the companies.

(10) At 31st December, 1918, the Municipalities had 237,000 kw. of load awaiting connection, and the Companies 121,000 kw.

(11) The units obtained other than by coal-firing were :—

| | |
|---|---|
| Oil fuel .. .. .. .. | 50,000,000 |
| Waste heat and gas .. .. | 215,000,000 |
| Water power .. .. .. | 23,000,000 |

(12) About 27,000 persons were employed in electric supply undertakings, of whom about 2,500 were women. Some 17,000 were employed by the Municipalities, and 10,000 by Companies.

**23.** *Increased output for power only.*—It can be stated without fear of contradiction that the whole of the increased output during the War was used for power, smelting, and other industrial purposes. The restrictions on public and private lighting, necessitated by military requirements, coal shortage, etc., must have prevented any expansion in the use of current for purely domestic purposes: in all probability there was in the aggregate a substantial diminution during the War.

**24.** *Pre-eminence of electricity as the motive power.*—It may be said that the War definitely established the pre-eminence of electricity as *the* motive power for industry. It is probable that the next decade will see a similar expansion in the use of electricity in industry as was experienced when steam plant was sufficiently developed to be applicable to industrial operations, and that great growth in the industries of the country generally will follow. During the War a large number of manufacturers who had previously little or no experience of the electric drive have become fully acquainted with its advantages and have realized, in particular, the desirability of purchasing current from public sources instead of generating it by separate power plants.

**25.** *Concentration of generation.*—It has been the Government policy during the War to encourage power users to obtain their requirements from the public service undertakings and to discourage the installation of separate small generating plants. There was undoubtedly a time when some large manufacturers and railway undertakings preferred to be self-contained and to generate their own current. This policy is, however, rapidly passing away, and in future the supply of electricity for power purposes will undoubtedly be purchased where public supplies are available; an incentive to this being the high cost of money and of plant. Manufacturers will be able to spend capital, which would otherwise be sunk in generating plant, to greater advantage on the machinery required to turn out their particular products.

**26.** *Private plants ordered.*—There were, however, considerable orders placed during the War for private electrical generating plants, particularly in connection with the many large extensions of iron and steel works. In most of these cases waste heat, in the form of exhaust steam from rolling-mill engines or gas from blast furnaces and coke-ovens, was to be used for electric power production, and private plant was therefore justified. Wherever possible, however, linking up with an adjacent public service electrical undertaking was arranged. At the end of 1918 the following turbo-generators were on order under Class A :—

| | |
|---|---|
| Municipalities .. .. .. | 228,000 kw. |
| Public service companies .. | 163,000 kw. |
| Private plants .. .. .. | 88,000 kw. |

**27.** *Financial policy of Government.*—The increasing cost of plant as the War continued, and the difficulty of financing extensions which might be larger than would be necessary for some time after the cessation of hostilities, soon raised questions requiring the settlement of a clearly defined policy. After full consideration, the Treasury decided that interest-bearing loans might be made, where necessary, to municipalities and companies, the loans generally being repayable by annual instalments over 15 years or so, and further, that the Ministry of Munitions might guarantee to bear the difference between the cost of carrying out extensions during the War and the estimated cost of the same work if carried out at some period after the conclusion of hostilities—this period as a rule being one year or two years post-war—and also the cost of any portion of the extensions found to be in excess of the post-war needs of the undertaking. In other words, the public service undertakings were to be put in the same position as they would have been if they had not extended during the War but had waited until their post-war requirements must be proceeded with.

**28.** This policy was found generally acceptable, and undoubtedly facilitated urgently-needed power station and mains extensions. While some applicants pressed for definite Government grants towards the excess War cost of extensions, it was generally recognized as fair that electric supply undertakings enjoying a monopoly and either perpetual or lengthy powers, and supplying a commodity needed after the War, were not entitled to grants in the same way as were manufacturing firms called upon to extend factories and manufacture products not required in post-war industry.

**29.** Of the £23,000,000 which it is estimated has been incurred on extensions of power houses and mains during the War, about £3,150,000 has been advanced by the Ministry of Munitions.

**30.** *Importance of supply to Woolwich Arsenal.*—It may be interesting to record the arrangements made for making as secure as possible the supply of electricity to Woolwich Arsenal. The number of employees at work in the Arsenal increased five-fold during the War. The maximum power load reached about 8,000 kw. In 1914 the much smaller supply was mainly derived from the small generating station at the Arsenal, supplemented by a supply taken from the electricity undertaking of the Woolwich Borough Council. These two sources combined were insufficient to meet the War requirements, and extensions of the Woolwich Borough Council generating station were accordingly put in hand. That undertaking was also linked up with the mains network of the South Metropolitan Electric Light and Power Company, Ltd., so as to secure a standby supply from the latter. In addition, cables were laid linking up the Arsenal with the Greenwich power house of the London County Council tramways undertaking, which, unfortunately, was a 25 cycle system, whereas the periodicity of the Woolwich Council's undertaking was 50 cycles. The supply from the London County Council was utilized primarily for operating rotary converters (direct current being mainly used at the Arsenal) and also for the supply to electric furnaces installed at the Arsenal for the production of steel from scrap material. The furnace transformers were provided with reactances, so that they could ultimately be operated at 50 cycles instead of 25 cycles if, after the War, the Woolwich Borough Council electricity undertaking was in a position to deal with the whole load at the Arsenal, which is situated in their statutory area of supply.

**31.** The arrangements above referred to were made, not only to provide the largely increased supply needed at the Arsenal, but also to secure greater reliability in the event of either of the supply undertakings being damaged by hostile aircraft.

**32.** *Electrical equipment for Russia.*—During the earlier period of the War, the Russian Government and Russian private firms were large buyers of electrical machinery and apparatus from Great Britain. The Ministry of Munitions eventually became somewhat anxious as to whether the plant ordered from time to time was being properly considered from the point of view of the carrying through of complete schemes, and at one stage it was felt desirable that the Electric Power Supply Department should send representatives to Russia to make sure that complete power stations were being provided. They could not, however, be spared for this mission.

**33.** During one of the upward curves of submarine attack, certain ships conveying electrical plant to Russia were sunk, and inevitable disorganization in Russian munition works followed. When the Russian debacle set in, the export of further electrical machinery to Russia was stopped. A considerable amount of plant was either ready for despatch or well in hand at the manufacturers' works. Some of the latter plant was completed and the rest put on one side but considerable congestion at the works followed. Fortunately, most of the generating plant was of 50 cycles, and consequently a fair percentage was sold to the electrical undertakings of municipalities and companies, and here and there this opportunity of acquiring plant quickly facilitated the more rapid production of certain War munitions.

**34.** *Electrical equipment for American Forces.*—After the entry of America into the War and the commencement of the establishment of their bases in France, the Ministry of Munitions despatched representatives of the Electric Power Supply Department to France to assist the Americans in procuring certain electrical machinery and equipment from England.

**35.** *Wayleaves.*—Whatever may have been the experience prior to the War, it can happily be said that where landowners were asked for wayleaves to enable underground cables or overhead lines to be carried across their property to facilitate the supply to munition works, such applications were readily granted. In only two or three cases were unreasonable objections raised, and it was generally sufficient to suggest that the powers conferred by the Defence of the Realm Acts would be exercised, if required. Only one case can be called to mind where it became necessary to cross land under the powers conferred by D.O.R.A.

**36.** *Policy of the Ministry of Munitions.*—To some extent the policy of the Electric Power Supply Department of the Ministry of Munitions has already been referred to. The functions exercised by the Department, however, covered duties other than the control of electric supply undertakings and manufacturers. In general, these functions were as follows:—

(*a*) Advising other Departments of the Ministry of Munitions, the Air Ministry, and some Departments of the Admiralty and War Office on all schemes where the installation of electric generating plant or motors, or the purchase of current from a public service undertaking was concerned.

(*b*) The granting of priorities or advising the Priority Department on the priorities necessary for electrical machinery.

(*c*) Controlling the manufacture of electrical generating plant, motors, transformers, etc., by the various electrical manufacturing firms in the country.

(*d*) Considering and approving all extensions of generating stations, and mains of the public service undertakings.

(*e*) Endeavouring, so far as possible, to secure the standardization of electrical manufacture.

(*f*) The negotiation of power-supply contracts where

power is purchased from public service undertakings for national factories.

(*g*) Advising on imports and exports of electrical machinery, and on the electrical requirements from British firms for Allied countries.

(*h*) Advising on all Mercantile Shipyard extensions involving the use of electric power.

**37.** As time went on and experience accumulated, various Government Departments became persuaded that closer co-operation between them on all questions concerned with electrical engineering was desirable. Accordingly, the War Cabinet Priorities Committee set up during 1918 the Electrical Services Sub-Committee, of which the Ministry of Munitions member was Chairman, and on which the following Government Departments were represented :—Ministry of Munitions, Admiralty, War Office, Board of Trade, Air Ministry, Local Government Board, and Scottish Office. As the Terms of Reference to this Committee may interest the electrical industry generally, they are set out in condensed form as follows :—

(1) To secure uniformity of practice in the use of electrical energy by Government Departments, and generally throughout the country.

(2) (*a*) To consider the requirements for electrical energy and plant and the consequent demands on power stations.

(*b*) To consider the capacity for electrical manufacture and how the demands likely to be made upon it for additional machinery can be met.

(3) To secure uniformity of power supply contracts and plant extensions.

In interpreting the above Terms of Reference—

(1) The Committee excluded from their purview :

(*a*) Purely naval and military requirements of the Fleet and of the Armies in the field, respectively.

(*b*) All applications from Government Departments for generating plant, for the purpose of providing power or light of less power than 200 h.p.

(2) The Committee were empowered :—

(*a*) To require that all applications should be submitted to them for their approval which emanated :

(i) From Government Departments for generating plant of over 200 h.p. for the purpose of providing power or light.

(ii) From all other sources for such generating plant of any horse-power.

(*b*) To consider cases referred to them in which the demands of Government Departments in connection with any particular branch of the electrical industry could not be met by the existing resources of the industry.

(*c*) To follow the general principles that—

(i) Electrical energy shall be purchased instead of separately generated wherever possible.

(ii) Current shall be used as "alternating" rather than "direct" wherever available and suitable.

(*d*) To require the submission of power supply contracts which it is proposed should be entered into between Government Departments or firms contracting on their behalf and public supply undertakings.

**38.** The appointment of this Committee was found of value in achieving the objects for which it was established.

**39.** *Co-operation to be extended.*—It is not improbable that the co-operation which was secured between Government Departments will be continued in Peace time. In this connection, the experience of the Armies in the Field emphasizes the importance of co-operation and standardization.

**40.** *Electric power in the Field.*—The use of electric power in the Field became of increasing importance as the war prolonged, and as the result of the experience gained it is most probable that the requirements of the Army for electrical equipment will increase both in peace and in war. The standardization of electrical machinery and closer co-operation between Government Departments is therefore more than ever of importance. It is common knowledge that the use of alternating rather than direct current should be encouraged even for use in the Field, and any difficulties faced and surmounted. The experience of the American Forces has demonstrated that if large numbers of troops have to act in a country far distant from home, electric power requirements are likely to be very large and of first importance. The standardization and interchangeability of electrical plant and apparatus effects large economies of money, man-power and effort, besides saving delay by the provision and pooling of stocks, stores and spare parts. The German forces found the establishment of an Electrical Battalion for each Army of vital importance, and military sites were carefully chosen after prior consideration had been given to their convenience from the point of view of electric power supply.

**41.** The British Commanders in the Field recognized the importance of providing the best electrical service for the Army, and early this year a Commission was set up by G.H.Q. France to investigate and report on the use of electric power in the Field. Mr. C. H. Wordingham, President of the Institution, was a valuable member of this Commission.

**42.** *Control exercised as lightly as possible.*—In exercising control of public service undertakings and electrical manufacturing firms, it was always the policy of the Electric Power Supply Department of the Ministry to endeavour to enforce restrictions as lightly as possible. Control in any shape or form must necessarily be irksome and irritating, but circumstances from time to time made it essential. In the earlier days priority certificates were granted to electric supply undertakings with considerable freedom, and where manufacturers were concerned no interference with their output was occasioned so long as such certificates could be produced. As labour and material became more and more restricted, control had necessarily to be somewhat more rigidly exercised.

**43.** *Restriction of converting plant.*—Only two Control Orders were issued by the Ministry of Munitions. The first, dated 5th April, 1918, restricted the manufacture

of converting plant (Converter Plant Control Order, 1918). It had been found that some power users, and shipbuilding firms in particular, hesitated to use the more readily available supply of alternating current in certain districts, owing to their previous familiarity with direct current only, and no amount of persuasion seemed to convince them that alternating current was equally, if not more, suitable. The enforcement of the Converter Plant Control Order did bring about a reduction in the demand for converting plant, and assisted the engineers of electrical undertakings to prove that alternating current was quite suitable for most operations, and subsequent experience proved to power users that their previous fears were ill-founded. There nevertheless remains a considerable amount of missionary work to be done in this direction. At the conclusion of hostilities, in spite of the Control Order, there were no less than 92,000 kw. of converting plant capacity on order under Class "A" certificates, although by far the larger proportion of this was required for the production of direct current for purposes where alternating current was unsuitable. The Converter Plant Control Order 1918 was cancelled on the 28th February, 1919, after 193 licences had been issued.

**44.** *Restriction of new connections.*—A critical situation in the coal industry arose consequent upon the withdrawals from mines of a large number of men between March and June 1918. The coal output of the country substantially diminished owing to this cause and the ravages of influenza epidemics, and the Coal Controller found it essential to take steps to ration the use of coal. This was not applied to power stations in consideration of the Ministry restricting the connection of new consumers to those wholly engaged upon the production of urgently required War munitions. The second Control Order was the Electricity (Restriction of New Supply) Order 1918 issued on 8th November, 1918. Concurrently with it the Coal Controller found it necessary to ration the use both of electricity and of gas for domestic purposes.

**45.** *Restriction of lead-covered cable.*—There was a time during the War when the shortage of lead supplies was acute, and when in order to meet the requirements for shrapnel at the Front the strictest economy in the lead consumption for commercial purposes was an absolute necessity. It was during this period that restriction in the use of lead-covered cable had to be enforced, and this undoubtedly hit some undertakings severely.

**46.** *Early removal of restrictions and control.*—The Electricity (Restriction of New Supply) Order 1918 was revoked on the 10th January, 1919, less than 2 months after the date of the Armistice, and the Converter Plant Control Order, which had never been harshly enforced, was cancelled on the 28th February, 1919, thus freeing the electric supply industry thenceforth from any restrictions so far as control by the Ministry of Munitions was concerned.

**47.** *Scrapping of wasteful plant encouraged.*—After the formation of the Department of the Coal Controller, close touch was kept between that Department and the Electric Power Supply Department of the Ministry of Munitions. Wherever munition firms derived their motive power from inefficient steam plants wastefully consuming coal, every encouragement was given to such firms to take advantage of the public supplies of electricity. Unfortunately, the possibilities of economy in this direction were limited by the difficulty of obtaining electrical equipments for factories, and not much could therefore be done.

**48.** *Coal Controller's information re wasteful coal-consuming plants.*—The Coal Controller's Department and the Coal Commission must have ample information concerning existing wasteful steam plants, and it would be a national misfortune if such data as has been collected is not turned to account as soon as possible, by taking action to ensure that these plants are speedily scrapped and the more efficient electrical equipment installed in lieu thereof. There is no doubt whatever that colossal waste is continuing in many parts of the country in the use of fuel for power-production purposes.

**49.** *Policy in dealing with power station extensions.*—In dealing with applications for priority certificates for power station extensions of electric supply undertakings, the Ministry of Munitions were not infrequently faced with difficult considerations. On the one hand there was the insistent and urgent demand for more and more current, and on the other hand the fact that the extension of some of the less modern and less efficient power stations should, if possible, be avoided. The recommendations of various Government Committee Reports as to the necessity for the reorganization of electric power supply throughout the country, and the lines on which it should proceed, were known, but until new legislation had been carried through the existing systems had more or less to be adhered to. While the extension of some existing inefficient stations was unavoidable, efforts were made in certain areas to arrange for extensions, or the linking up of undertakings, in accordance with the latest recommendations and modern practice. A reference to some of these schemes will be of interest.

**50.** *Yorkshire and Lincolnshire development.*—One of the most important industrial areas in the country is that embracing Sheffield, Rotherham, the Yorkshire Electric Power Company's territory, the South Yorkshire coalfield, and the Lincolnshire ironstone area. Applications for power plant to serve all these areas were being separately received. In November 1917 a Conference of all parties interested was held at Sheffield and was largely attended by representatives of the interests referred to and of the large manufacturing firms in the district.

**51.** The importance of establishing power stations to the latest design and with the largest units for the purpose of serving the wide area above outlined was realized, and a representative committee was appointed to investigate thoroughly what in the common interest should be done. This Committee subsequently held several meetings and decided to call for a joint report from Sir John Snell and Mr. C. H. Merz, who were to advise what was the best scheme to adopt to serve an area which in extent was approximately 1,200 square miles. This report was in due course presented, and

it recommended the construction of new power houses on the River Trent for the service of the whole area, and that no further extensions of existing stations or the construction of new stations other than on the Trent or to utilize waste heat should be contemplated. Action on this report is awaiting the result of the Electricity Bill now before Parliament.

**52.** *Development in the Black Country.*—Consideration was also given to the Midlands. Throughout the War the Birmingham Corporation were unable to install generating plant sufficient to cope with all demands made from time to time. A similar state of affairs existed in the adjacent area served by the Shropshire, Worcestershire, and Staffordshire Electric Power Company. These two undertakings were fortunately of the same periodicity, namely 25 cycles, and it was therefore obvious that efforts should be made to link them together so far as the generation of current was concerned.

**53.** The Ministry of Munitions therefore moved in the matter, and various meetings of representatives of the two undertakings were held. The Birmingham Corporation was anxious to make a substantial commencement with the proposed permanent generating station at their Nechells site and the Power Company had acquired a large site on the river at Stourport, upon which they desired to erect the first section of a modern power house.

**54.** The arrangement first proposed was that a commencement should be made on each site by the erection of two 15,000-kw. sets, with boilers to steam both sets in each case, and to link up the two power houses by 33,000-volt cable via Smethwick.

**55.** The arrangements at one time under consideration were that the cost of the scheme should be advanced by the Government, and that the power stations, when constructed, should be operated by a Joint Board of Representatives of the Corporation and the Company respectively, pending the establishment of a District Board, if set up as the result of legislation on the lines of the Report of the Board of Trade Electric Power Supply Committee. The costs of operating the stations were to be pooled, and current taken by the Corporation or the Company, as the case may be, was to be paid for at the average cost per unit.

**56.** Unfortunately it was decided, no doubt quite rightly, that the new legislation could not be anticipated, and that Government moneys could not therefore be utilized in the way proposed. It is, however, now clear that the scheme could not have in any way conflicted with the provisions of the Electricity Bill recently introduced.

**57.** In view, however, of this decision, it was decided that, as the Birmingham area more urgently needed additional generating plant, the installation of two 15,000-kw. sets at Nechells should proceed, and this scheme is now well in hand, the Corporation financing the extension themselves and undertaking to provide the Power Company with a substantial supply in bulk.

**58.** The potential demand for current in the Black Country is so great that further steps to provide the area with an adequate supply of current will have to be taken without delay.

**59.** *Development in other industrial areas.*—In the great industrial areas of the Tyne and Clyde and Manchester, power station extensions more or less kept pace with demands, but in the brine and chemical area of Cheshire the production of poison gas could have been materially hastened and augmented had an electric power supply system for the district been available. This area is now being dealt with.

**60.** *Public plants sanctioned by Ministry.*—Of the total of 103 Municipal, and 34 Company extensions, 70 of the Municipal and 22 of the Company schemes were considered and sanctioned by the Ministry of Munitions. The remainder were presumably put in hand before the priority system was established. The plant capacity involved was :—

| | |
|---|---|
| 70 Municipalities .. .. | 697,000 kw. |
| 22 Companies .. .. | 330,000 kw. |

**61.** *Ministry of Munitions staff.*—In view of the criticisms, some just and some unjust, directed from time to time against the large numbers employed by Government Departments, it may be recorded that the personnel of the Electric Power Supply Department at no time exceeded 7 men and 14 women.

**62.** *The great achievement of electrical supply undertakings.*—It is impossible to conclude this record of the war burden borne by the public electric supply undertakings without a word of appreciation as to the value of the services they rendered. Upon those undertakings centred in industrial areas the heaviest work necessarily fell. The weight carried by the chief engineers, managers and their staffs can only be adequately appreciated if the following facts are borne in mind :—

**63.** Electric supply undertakings were mostly manned by men of military age—a circumstance unavoidable in a youthful industry. It was natural that a large number of young engineers were anxious to join the Forces, and many of them were allowed to go. It was with great difficulty that the remainder were prevailed upon to stay, and it was only owing to the action of the Government in making electrical undertakings "Certified," and by the issue of badges, that undertakings were not dangerously denuded of trained men. The doubling of the output of electricity during the War is an indication of the serious consequences that would have followed, had all who wished to see active service been permitted to join up.

**64.** Upon those remaining abnormal difficulties fell, for the bad quality of coal, anxieties about deliveries, shortage of generating plant, and the impossibility to take machinery out of operation for necessary overhauls meant a constant strain.

**65.** It is to the credit of the public service electric supply undertakings that the supply of current throughout the War was maintained in nearly every part of the country practically uninterruptedly. The record for reliability is a matter for both pride and satisfaction, especially when the abnormal difficulties referred to are remembered.

**66.** In only one or two minor instances was the supply of current interrupted through temporary breakdowns, and munitions output retarded in consequence. This

reliability of the public service redounds to the credit of the responsible engineers and their staffs, and is a good augury for the confidence with which manufacturers can, when normal conditions return, rely upon the supply from public undertakings.

**67.** Again, there was not, as was the case with most manufacturing firms, the incentive of increased profits to be earned. The electric supply undertakings which paid excess profits during the War can be counted on the fingers of one hand. By far the larger number of them have had to raise their prices substantially to keep expenses—increased by the rising wages, cost of coal, stores and repairs, etc.—below receipts.

**68.** There were many stations in which shift men worked 12 hours a day instead of eight, to fill the gaps made by the drain of their colleagues to the Army and Navy.

**69.** When all these circumstances are taken into account, it is not easy to express adequately the value of the services rendered by electrical engineers. The 4 years of war saw practically a development of electrical output equivalent to that of the previous 32 years. This record of increased output for which they have been responsible can perhaps be allowed to stand as the most fitting testimony of their great war achievement. They have well merited and earned the gratitude of the Nation and of every Department of the Ministry of Munitions concerned with the production of munitions of war.

List of Municipal Electricity Supply Undertakings which have Installed or Ordered Additional Generating Plant between 30th June, 1914, and 31st October, 1918.

| Name of Corporation | Plant Capacity at 30th June, 1914 kw. | Additional Plant Installed or Authorized. Period 30th June, 1914, to 31st Oct., 1918 kw. |
|---|---|---|
| 1. Aberdeen | 8,380 | 9,380 |
| 2. Accrington | 4,888 | 1,500 |
| 3. Alloa | 309 | 1,607 |
| 4. Ayr | 1,100 | 1,500 |
| 5. Barking | 930 | 1,000 |
| 6. Barnsley | 1,795 | 1,000 |
| 7. Barrow-in-Furness | 2,525 | 5,000 |
| 8. Batley | 800 | 1,200 |
| 9. Battersea | 5,092 | 5,000 |
| 10. Bedford | 1,945 | 2,305 |
| 11. Belfast | 13,300 | 10,500 |
| 12. Bexley | 500 | 500 |
| 13. Birmingham | 33,000 | 51,650 |
| 14. Bolton | 7,600 | 10,900 |
| 15. Bo'ness | 500 | 500 |
| 16. Bradford | 16,800 | 27,450 |
| 17. Brighton | 12,100 | 4,000 |
| 18. Bristol | 15,050 | 9,000 |
| 19. Burnley | 3,890 | 1,680 |
| 20. Burton | 2,700 | 4,200 |
| 21. Bury | 5,700 | 3,000 |
| 22. Cardiff | 8,200 | 3,000 |
| 23. Carlisle | 2,670 | 2,880 |
| 24. Chesterfield | 1,800 | 2,320 |
| 25. Coventry | 12,000 | 13,200 |
| 26. Darlington | 3,200 | 5,800 |
| 27. Dartford | 1,300 | 1,000 |
| 28. Derby | 7,050 | 7,500 |
| 29. Dewsbury | 2,000 | 500 |
| 30. Edinburgh | 17,980 | 2,500 |
| 31. Erith | 2,000 | 1,700 |
| 32. Exeter | 1,500 | 1,000 |
| 33. Farnworth | 650 | 500 |
| 34. Fulham | 4,450 | 2,700 |
| 35. Glasgow | 54,900 | 99,050 |
| 36. Greenock | 11,900 | 21,100 |
| 37. Hackney | 4,800 | 13,400 |
| 38. Halifax | 7,500 | 5,500 |
| 39. Hampstead | 5,889 | 1,500 |
| 40. Hereford | 810 | 2,000 |
| 41. Heywood | 900 | 600 |
| 42. Huddersfield | 7,450 | 4,000 |
| 43. Hull | 10,210 | 5,000 |
| 44. Ipswich | 3,500 | 3,000 |
| 45. Keighley | 4,620 | 5,380 |
| 46. Kettering | 1,510 | 1,250 |
| 47 Kilmarnock | 3,000 | 7,000 |
| 48. Kingston | 1,410 | 2,000 |
| 49. Kirkcaldy | 2,300 | 700 |
| 50. Leeds | 22,940 | 33,660 |
| 51. Leek | 515 | 200 |
| 52. Leicester | 7,450 | 6,000 |
| 53. Leigh | 1,100 | 1,500 |
| 54. Liverpool | 37,000 | 10,000 |
| 55. L.C.C. Tramways | 38,500 | 9,000 |
| 56. Londonderry | 1,200 | 2,500 |
| 57. Loughborough | 700 | 2,150 |
| 58. Luton | 2,450 | 10,000 |
| 59. Maidstone | 2,075 | 1,900 |
| 60. Manchester | 72,300 | 46,450 |
| 61. Newport | 7,100 | 3,000 |
| 62. Norwich | 4,850 | 3,000 |
| 63. Nuneaton | 1,200 | 950 |
| 64. Oldham | 5,340 | 7,050 |
| 65. Paisley | 4,200 | 8,200 |
| 66. Perth | 1,175 | 500 |
| 67. Peterborough | 840 | 500 |
| 68. Plymouth | 5,475 | 4,800 |
| 69. Poplar | 10,000 | 4,250 |
| 70. Portsmouth | 4,450 | 2,000 |
| 71. Rawtenstall | 3,331 | 2,000 |
| 72. Redditch | 690 | 4,770 |
| 73. Rochdale | 5,476 | 5,780 |
| 74. Rotherham | 5,150 | 65,350 |
| 75. St. Helens | 4,500 | 3,000 |
| 76. St. Pancras | 8,850 | 3,000 |
| 77. Salford | 8,500 | 9,500 |
| 78. Sheffield | 23,225 | 73,000 |
| 79. Shipley | 1,000 | 3,000 |
| 80. Shoreditch | 5,680 | 5,000 |
| 81. Southampton | 5,500 | 3,000 |
| 82. South Shields | 3,800 | 2,000 |
| 83. Southwark | 1,800 | 1,500 |
| 84. Stepney | 7,720 | 9,480 |

| Name of Corporation | Plant Capacity at 30th June, 1914 kw. | Additional Plant Installed or Authorized. Period 30th June, 1914, to 31st Oct., 1918 kw. |
|---|---|---|
| 85. Stockport .. .. | 4,850 | 11,150 |
| 86. Sunderland .. .. | 8,500 | 7,500 |
| 87. Swansea .. .. .. | 5,100 | 5,000 |
| 88. Swindon .. .. .. | 1,400 | 2,000 |
| 89. Tonbridge .. .. | 370 | 570 |
| 90. Wakefield .. .. | 2,250 | 1,500 |
| 91. Wallasey .. .. | 2,400 | 4,600 |
| 92. Walsall .. .. .. | 2,490 | 5,500 |
| 93. Walthamstow .. .. | 4,160 | 2,706 |
| 94. Warrington .. .. | 3,150 | 4,900 |
| 95. West Bromwich .. | 3,300 | 4,000 |
| 96. Wigan .. .. .. | 4,820 | 6,500 |
| 97. Wimbledon .. .. | 3,325 | 1,500 |
| 98. Wolverhampton .. | 7,050 | 16,450 |
| 99. Woolwich .. .. | 2,850 | 6,650 |
| 100. Worcester .. .. | 3,750 | 1,500 |
| 101. Yarmouth .. .. | 2,075 | 600 |
| 102. York City .. .. | 3,900 | 3,500 |
| 103. Stalybridge .. .. | 18,000 | 1,000 |
| Totals .. .. | 704,955 | 784,068 |

List of Company Electricity Supply Undertakings which have Installed or Ordered Additional Generating Plant between 30th June, 1914, and 31st October, 1918.

| Name of Company | Plant Capacity at 30th June, 1914 kw. | Additional Plant Installed or Authorized. Period 30th June, 1914, to 31st Oct., 1918 kw. |
|---|---|---|
| 1. Altrincham .. .. | 1,600 | 1,500 |
| 2. Bournemouth and Poole | 4,000 | 4,600 |
| 3. Brompton and Kensington .. .. .. | 3,000 | 1,500 |
| 4. Central Electric .. .. | 26,283 | 7,570 |
| 5. Charing Cross .. .. | 23,480 | 3,000 |
| 6. City of London .. .. | 27,000 | 6,000 |
| 7. Clyde Valley .. .. | 35,000 | 37,500 |
| 8. Cornwall .. .. .. | 6,745 | 3,000 |
| 9. County of London .. | 19,800 | 14,400 |
| 10. First Garden City .. | 550 | 1,890 |
| 11. Isle of Thanet .. .. | 1,900 | 600 |
| 12. Kensington and Knightsbridge .. .. .. | 9,390 | 500 |
| 13. Lancashire Electric .. | 16,500 | 6,000 |
| 14. Leicester and Warwick .. | 1,700 | 1,250 |
| 15. Llanelly .. .. .. | 1,600 | 2,700 |
| 16. London Electric Supply | 25,450 | 12,000 |
| 17. Mersey Power Co. .. | 4,900 | 24,500 |
| 18. Metropolitan .. .. | 22,500 | 4,000 |
| 19. Midland Electric .. .. | 10,600 | 10,200 |
| 20. National Electric.. .. | 2,630 | 560 |
| 21. Newcastle-upon-Tyne and Associated Companies | 86,200 | 114,200 |
| 22. Newcastle and District .. | 9,000 | 8,000 |
| 23. Northampton .. .. | 3,640 | 3,500 |
| 24. North Metropolitan .. | 16,122 | 21,068 |
| 25. Scottish Central .. .. | 3,300 | 6,230 |
| 26. Shropshire, Worcestershire and Staffs .. | 28,325 | 15,850 |
| 27. Slough and Datchet .. | 695 | 1,335 |
| 28. South Metropolitan .. | 6,000 | 15,000 |
| 29. South Wales .. .. | 10,500 | 5,000 |
| 30. Trafford .. .. .. | 5,200 | 7,950 |
| 31. Uxbridge and District .. | 1,030 | 3,650 |
| 32. Woking .. .. .. | 1,100 | 1,000 |
| 33. Yorkshire Electric .. | 14,300 | 12,000 |
| Totals .. .. | 430,240 | 358,053 |

Note.—The above lists have been compiled as accurately as possible from somewhat imperfect records, and they are believed to be substantially correct.

(Part II of the paper will be published later.)

# THE SUSCEPTIBILITY OF FEEBLY MAGNETIC MATERIALS.

## ADDRESS TO THE STUDENTS' SECTION.

By Professor Ernest Wilson, Member.

(*Address delivered 22 November*, 1918.)

The engineer is accustomed to use the ratio of the magnetic induction B to the magnetic force H when defining permeability; and a statement to the effect that the maximum susceptibility of a piece of pure iron is 400 C.G.S. units might possibly convey little or nothing to his mind. When the permeability of feebly magnetic substances is in question a better idea of relative magnitude is, however, conveyed by the use of susceptibility rather than permeability. The two are related by the equation $\mu = 1 + 4\pi\kappa$; where $\mu$ is the permeability as ordinarily defined, and $\kappa$ is the volume-susceptibility.

As an example, suppose it is desired to compare the above susceptibility of 400 with the susceptibility of, say, tin. If permeabilities are in question the ratio is 5,000 : 1·0000044, or very closely 5,000 : 1; whereas the ratio of the susceptibilities is $400 : 0{\cdot}35 \times 10^{-6} = 10^9$ nearly. The volume-susceptibility $\kappa$, however, takes no account of the density of the material, and there are those who prefer to use what is termed "mass-susceptibility," which is the ratio of $\kappa$ to the density. Further proposals in which the atomic weight of the substance is involved have been made. In what follows the volume-susceptibility $\kappa$ is referred to.

As regards the measurement of low values of susceptibility, the ordinary methods employed in the case of iron are quite out of the question. The ordinary magnetometer ceases to be applicable when values lower than about 0·001 are in consideration, and even when the magnetometer is supplemented by an induction balance Rücker considered that 0·00013 represented about the lowest reliable minimum which could be measured.

The instrument to be presently shown in action is capable of dealing with values of susceptibility (positive or negative) of exceptionally low order, and the principle underlying its action is given by Maxwell in the equation $F = \kappa \frac{1}{2} \frac{d\,H^2}{d\,x}$; where F is the force acting upon unit volume of the substance and H is the magnetic force varying with the distance $x$. Briefly described, it consists of an electromagnet which attracts or repels the substance according as it is para- or dia-magnetic. The specimen is fixed to one end of a horizontal beam which is supported at its centre by a phosphor-bronze strip, and the pull exerted by the magnet is balanced by the force of torsion in the strip. Normally the specimen hangs between the poles of the magnet which is capable of motion in a horizontal plane at right angles to the beam. When making a determination of susceptibility the electromagnet has impressed upon it a suitable magnetizing force which is maintained constant, and it is moved forward, thus attracting the specimen in the direction $x$ until the angle of twist is a maximum: and this is indicated by a spot of light on a scale after the manner of an ordinary reflecting galvanometer. Knowing the strength of the magnetic field H and the volume of the specimen V, the susceptibility $\kappa$ is calculated from the equation $\kappa = C\,\theta/H^2\,V$; where $\theta$ is the observed maximum deflection and C is a constant.

The following table gives a selection of substances with their susceptibilities, which in some cases are approximate and have been chosen as illustrative examples. [The instrument was then used to demonstrate experimentally how solids, powders, and fluids can be dealt with. By aid of an arc lamp a spot of light was thrown on a scale distant about 20 feet in order that the deflections could be observed by those present.]

Table of Volume-susceptibilities in C.G.S. Units.

| | |
|---|---|
| Magnetite crystal | 10 (max.) |
| Magnetite calcite | 0·13 |
| Magnetite (so-called), down to about | 0·1 |
| Sulphide of iron | 0·064 |
| Dolerite (a piece of) | 0·0045 |
| Granite (a piece of) | 0·0012 |
| Ironstone | 0·00030 |
| Red hæmatite | 0·00020 |
| Platinum | 0·000029 |
| Manganese sulphate (normal solution) | 0·000017 |
| Ferrous sulphate (normal solution) | 0·000015 |
| Bengal ruby mica, clear, in direction parallel to plane of laminæ | 0·000012 |
| Limestone | 0·000006 |
| Aluminium | 0·0000018 |
| Copper | −0·00000073 |
| Tin | 0·00000035 |
| Glasses (various) | −0·00000015 to +0·0000025 |
| Water | −0·00000075 |

*Iron compounds.*—The black oxide of iron, $Fe_3O_4$, known as magnetite occurs in nature crystallized in octahedra and is formed when iron is oxidized at a high temperature. It is remarkable that its suceptibility should be so much higher than that of the ferrous and ferric oxides. Its curve of magnetization resembles that of iron itself, and like iron it ceases to be magnetizable at high temperatures—its transformation temperature being from 535 to 550° C It is largely

found in igneous rocks, and it has been estimated that at about a depth of 12 miles it has reached the non-magnetic stage. Large deposits of magnetite are found near the earth's surface, the most remarkable perhaps being that in Sweden which has been estimated to have a volume of $192 \times 10^6$ cubic metres or a weight of $865 \times 10^6$ metric tons.

As an illustration of the use of powders, some New Zealand iron sand was placed in a glass tube and its susceptibility measured. This extraordinary deposit exists for many miles along the seashore and has the following percentage composition :—

| | |
|---|---|
| Peroxide of iron .. .. | 52·88 |
| Protoxide of iron .. .. | 29·60 |
| Alumina .. .. .. | 0·90 |
| Protoxide of Mn .. .. | 0·48 |
| Magnesia .. .. .. | 4·00 |
| Silica .. .. .. .. | 3·80 |
| Titanic acid .. .. .. | 8·41 |
| Oxide of cobalt .. .. | trace |
| Phosphoric acid .. .. | none |
| Sulphur .. .. .. | none |

The sand is rich in iron and free from sulphur and phosphorus, the difficulty at first experienced in smelting being due to the mechanical condition and the presence of titanic acid. Soft iron made from this sand was tested and found to have excellent magnetic properties. Taken on superficial or apparent volume the susceptibility of this sand is 0·143. It may be here remarked that the susceptibility of solid rocks can be fairly closely inferred from measurements made with them when reduced to powder.

Ferrous oxide, FeO, and ferrous salts are more highly magnetic than the ferric varieties. Ferrous oxide colours glass green and gives the peculiar tint to glass bottles. The high positive susceptibility of certain glasses (see Table) is largely due to ferrous salts, which may also account for the relatively high susceptibility in green tourmaline.

Cast iron is manufactured in England from clay ironstone which generally occurs in the neighbourhood of coal. The ironstone (ferrous carbonate with clay) after roasting, during which operation the carbonic acid is driven off and ferric oxide formed, together with limestone and coal is fed into the blast furnace. The author is indebted to the Holwell Iron Company, Asfordby, near Melton Mowbray, for the samples of ironstone obtained from their workings, together with the subjoined analyses.

Sample A is from the workings situated on the outcrop of the Northampton sands exposed over the area between the villages of Buckminster and Sewstern, Gunby, and Skillington in the counties of Leicester and Lincoln.

Sample B is the same stone after calcination on open heaps or "clumps" at the quarries.

Sample C of marlstone, ordinary or soft ironstone.

Sample D of marlstone (Middle Lias) quarried near the village of Eaton in the county of Leicestershire —this is a sample of "limey" ironstone.

Analyses

| | A | B | C | D |
|---|---|---|---|---|
| Iron .. .. | 34·10 | 45·00 | 31·80 | 26·10 |
| Manganese .. | 0·33 | 0·45 | 0·31 | 0·32 |
| Phosphorus .. | 0·73 | 0·98 | 0·34 | 0·32 |
| Silica .. .. | 15·50 | 21·50 | 12·70 | 10·90 |
| Alumina .. | 5·60 | 7·50 | 10·10 | 7·40 |
| Lime .. .. | 0·68 | 0·84 | 3·12 | 10·50 |
| Magnesia .. | 0·35 | 0·45 | 0·68 | 0·73 |
| Sulphur .. | 0·08 | 0·09 | 0·06 | 0·06 |
| Moisture .. | 17·00 | — | 14·00 | 12·00 |

The susceptibility of these ores in which the iron content is considerably smaller than in hæmatite is of the order 0·0003.

As an illustration of the effect of roasting, a piece of hornblende (ferrous silicate) was powdered and its susceptibility found to be 0·00033—after roasting the susceptibility was 0·00025.

Ferric oxide, $Fe_2O_3$, occurs in nature as the minerals red hæmatite and specular iron ore, and when combined with water it forms brown hæmatite. The table shows that the susceptibility of red hæmatite which is rich in iron is only 0·0002.

As a further example of the complexity of the subject it may be mentioned that iron sulphide (FeS) has a comparatively high susceptibility of 0·064; whereas iron pyrites ($FeS_2$) is feebly magnetic. [A normal solution of manganese sulphate was placed in a glass tube and tested in the balance.] Manganese and ferrous sulphates (normal solutions) afford another example of the importance of not prejudging magnetic susceptibility merely from the standpoint of iron content. The phenomenon of magnetism can be produced by the combination of what would individually be called non-magnetic materials. Finally the susceptibility of a specimen of mica was obtained, and it was shown to be considerably larger in the direction of the laminations than at right angles thereto.

Apart from the scientific interest of the subject a knowledge of the susceptibility of feebly magnetic materials has assumed some importance in connection with magnetic survey work. It is also important in problems which deal with the magnetic separation of ores.

# PROCEEDINGS OF THE INSTITUTION.

## 625TH ORDINARY MEETING, 6 MARCH, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 27th February, 1919, were taken as read, and were confirmed and signed.

Messrs. H. C. Healey and T. H. Langford were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

### ELECTIONS.

*Members.*

Hippisley, Richard John B., O B.E.
Roberts, Frederick William.
Roberts, William.

*Associate Members.*

Ackery, Alan Philip.
Allen, John Tamlyn.
Austin, Tom.
Backhouse, Laurence.
Badger, William Thomas.
Bagnall, Robert Ironside.
Barlow, Cecil John B.
Brodie, John.
Brown, William Arthur.
Carter, Harley Autton.
Chellingworth, Albert Arthur.
Clarke, Harry Bell.
Cooper, George Wolfenden.
Coventon, George Lemon.
Craufurd, Quentin Charles A., Commander, R.N.
Cumming, James Edward.
Dyer, Herbert Hedley.
Evans, Griffith Heber D.
Falle, Harold de Carteret.
Fletcher, George Herbert.
Gould, Ernest Henry.
Graham, Stanley Wilson.
Gregg, Harry.
Hall, John Courtenay.
Hancock, William Upton.
Harvey, James Leonard.
Hollins, Trevor.
Howell, William James E.
Hurford, George.
Hyland, James George H.
Kernick, Theodore Richard.
Lees, Arnold.
Lewis, Gwilym John.
Lingard, Thomas Menzies.
McGregor, John Johnston.
McKee, Francis Joseph.
Malone, James Joseph.
Marston, William Joseph.
Mercer, Eli.
Morgan, Albert, Lieut., R.F.A.
Narayan, Shiv, M.A., B.Sc., B.E.
Orchard, Frederick Arthur.
Parker, Henry Charles.
Rees, Joshua Palmer.
Roles, Frederick William.
Rowe, Josiah Arthur V.
Rubie, George Henry.
Sawyer, Ernest Walker.
Sennitt, Randolph Branch.
Sharp, John Thomas.
Sinclair, Alexander Vaughan.
Smith, William Grosvenor.
Spencer, Thomas George.
Struthers, John Russell.
Topham, Harry.
Trees, Thomas Dennis.
Valentine, John Hugh.
Ward, Bernard Cecil P.
Warren, Aubrey Grenville.
Watkins, William Aston.
White, Henry Orme.
Woods, Richard Charles.
Wright, Victor Albert.
Xenaky, Reginald.

*Associates.*

Bellhouse, Charles.
Harding, Stanley James.
Jack, George Cameron.
Jenkins, Francis Thomas, Lieut.
Maclean, James Borrowman.
Walker, William Peto.

*Graduates.*

Ashby, Ernest William.
Coates, Francis Stirling.
Cousins, Harold Francis.
Davis, Basil Montefiore J.
Davis, Edward Saul.
Dawson, Edmund Daine.
Deaville, Edward.
Dover, Henry James.
Fenner, Leslie George.
Francis, Thomas George, 2nd Lieut., R.E.
Garbutt, Sydney.
Garnett, Albert.
Johnston, Harry Hugh.
Laird, John Andrew.
Lowrey, Amos Spalding.
Mason, William John.
Nogueira, Antonio de Amaral.
Passmoor, John.
Riley, Thomas.
Smith, Herbert.
Stacey, Clarence John.
Trill, Frederick Francis.
Wicks, William Edgar.

*Students.*

Ash, Ronald Henry H.
Bartlett, Sydney John.
Bowen, William James N.
Browning, Alan John.
Carter, Henry Edmond D.
Davidson, Russell Hawes.
Edwin, Hugh Stanley.
Evans, Clive Walter.
Fowler, George Henry.
Gledhill, Eric.
Grinstead, Leslie.
Hawkins, Raymond Cecil.
Henderson, John Alfred.
Herbert, Robert Henry.
Hines, Ronald John.
MacDowell, Maurice Alfred
Murphy, Hugh Stewart.
Pegg, Arthur Crosskill.
Pemberton, Roland Thomas
Platt, Claude Bernard, Capt., R.E.
Price, Thomas Willis.
Russell, Robert.
Saunders, Laurence Henry.
Selitrenny, John Lionel.
Stephenson, George Arthur E.
Stratton, John.
Taylor, Herbert Willott.
Wade, John Charles.
Walton, Edward Soilleux.
Ward, George.
Waterhouse, Clifford Thwaite.
Webster, Herbert.
Whillance, John C.
Wild, William Thomas B.
Wright, Frank.

### TRANSFERS.

*Associate Member to Member.*

Bacon, Professor Frederic, M.A.
Coates, Albert Frederick.
Crosbie, Charles Wilson.
Furse, William Francis.
Kemp, James Pattison.
McLachlan, Norman W., D.Sc. (Eng.).
Morton, Frank.
Willis, Robert Wickham.

*Graduate to Associate Member.*

Cheal, Arthur Ernest E., Capt.
Collyer, George, M. C.
Hopkins, Allan Valentine.
McDermott, James.
Spary, Percy George.

*Student to Associate Member.*

Davies, George Faraday.
do Rio, Ernesto Alves.
Mittell, Brenchley Ernest G., Capt., R.E.
Peter, Leslie Hurst, M.C.

*Student to Graduate.*

Chowna, Cawasjee Pallonjee, B.A.
Coombs, Kenneth.
Fathers, Leslie J.

*Student to Graduate*—continued.

Griffith, John Eaton.
Jenkins, Alfred Millard, B.Sc., Lieut., R.E. (T.).
Knobel, Johann Ludwig.
Ramaswami, Erode K.
Waddington, Oswald Vernon.

The PRESIDENT announced the arrangements for the first four Informal Meetings (see *Institution Notes*, No. 11, page 18, February 1919).

Mr. G. L. Addenbrooke, Member, then delivered his second lecture on "Dielectrics in Electric Fields." A vote of thanks to the lecturer, proposed by the President, was carried with acclamation and the meeting adjourned at 7.5 p.m.

## 626TH ORDINARY MEETING, 13 MARCH, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 6th March, 1919, were taken as read, and were confirmed and signed.

A list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

A vote of condolence was passed with the families of the late Mr. J. P. Tierney, Chairman of the Irish Centre, and the late Mr. A. Reyrolle, Member, the members standing in silence.

The third lecture on "Dielectrics in Electric Fields" was then delivered by Mr. G. L. Addenbrooke, Member.

A vote of thanks to the lecturer was carried with acclamation and the meeting adjourned at 7.25 p.m.

## 627TH ORDINARY MEETING, 20 MARCH, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 13th March, 1919, were taken as read, and were confirmed and signed.

Messrs. L. J. Rouard and A. T. Morris were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

### ELECTIONS.

*Students.*

Atkins, Leslie John.
Beckett, Charles Murray.
Brierley, Herbert.
Butcher, John Henry.
Frost, Ronald Arthur.
Gundry, John Arnold.
Hargreaves, Harold.
Hill, Norman Bartlett.
Hobson, Ralph Silvanus.
Lemon, Edward Noel K.

*Students*—continued.

Lissenden, Percival Horace.
Orvell, William.
Pittaway, Kenneth.
Rice, Nelson Redvers.
Rochester, Herbert Marmaduke.
Roulson, William Percy.
Shklovsky, George Edward
Steadman, Eric.
Stewart, Francis P.
Warner, Arthur George.
Wood, Alfred Russell.

### TRANSFERS.

*Associate to Member.*

Devonshire, James.

*Student to Graduate.*

Jones, John Williams.
Metcalf, James Norman.

A discussion was held on the subject of "Dielectrics," and the meeting adjourned at 7.55 p.m.

## 628TH ORDINARY MEETING, 21 MARCH, 1919.

(Joint Meeting with the Electrical Section of the Royal Society of Medicine held at 1, Wimpole-street, W 1.)

The chair was first taken at 8 p.m. by Dr. C. R. C. Lyster, President of the Royal Society of Medicine, who vacated it later in favour of Mr. C. H. WORDINGHAM, C.B.E., President of the Institution.

Two papers by Mr. R. S. Whipple, Member, entitled "Some Notes on Electrical Methods of Measuring Body Temperatures," and "Some Notes on the Electro-Cardiograph" respectively, were read and discussed and the meeting adjourned at 10.30 p.m.

## 629TH ORDINARY MEETING, 27 MARCH, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meetings of the 20th and 21st March, 1919, were taken as read, and were confirmed and signed.

A list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The following donations were announced as having been received and the thanks of the meeting were accorded to the donors :—

*Building Fund.*—W. M. Mordey.

*Benevolent Fund.*—A. H. Allen, G. Allom, H. T. Bates, S. Beeton, R. F. P. Blennerhassett, R. H. Campion, F. S. Carter, H. C. Channon, S. K. Chatterjee, R. A. Chattock, A. R. Chaytor, F. W. Clements, W. C. Clinton, H. Creagh, F. R. Davenport, B. Davies, J. Devonshire, F. T. C. Emberton, L. H. Euler, E. Garcke, F. Gill, Sir R. T. Glazebrook, C.B., F.R.S., G. F. C. Gordon, E. T. Goslin, C. W. Gwyther, H. T. Harrison, C. C. Hawkins, H. J. Henwood, J. S. Highfield, H. C. Holroyd, H. J. Howard, E. S. Jacob, W. Judd, A. C. Kelly, G. W. Kidd, H. Kitchen, T. E. Lewis, J. R. P. Lunn, Professor T. Mather, F.R.S., S. W. Melsom, L. B. Miller A. H. Morse, W. C. Mountain, J. Y. Nelson, Colonel A. M. G. Ogilvie, C.B., R.E., C. Oliver, E. Parry, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, F. G. Payne, H. L. Percy, A. P. Pyne, T. Rich, H. R. Rivers-Moore, A. S. Robertson, R. Robertson, W. R. Rogers, S. R. Roget, P. Rosling, W. Routledge, Captan H. R. Sanders, A. Siemens, S. B. Smith, C. P. Sparks, C. Stewart, E. E. Tasker, A. P. Trotter, G. K. Tweedy, C. Vernier, A. C. Wilmot, W. Wilson, J. H. Woodward, H. E. Yerbury, and A. Zoller.

A paper by the late Mr. H. R. Constantine, M.Sc. (Tech.), Associate Member, entitled " The Co-ordination of Research in Works and Laboratories," which had been awarded the prize offered by the Council for a paper on that subject (see *Institution Notes*, No. 7, p. 25, June 1918), was read by Mr. J. S. Highfield, Member, and discussed, and the meeting adjourned at 7.55 p.m.

## 630TH ORDINARY MEETING, 3 APRIL, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM. C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 27th March, 1919, were taken as read, and were confirmed and signed.

A vote of condolence was passed with the family of the late Dr. Henry Wilde, F.R.S., Honorary Member, the members standing in silence.

Lieut.-Col. A. G. T. Cusins, R.E., then delivered a lecture on " The Development of Army Wireless during the War."

A vote of thanks to the lecturer, proposed by the President, was carried with acclamation.

The meeting adjourned at 7.30 p.m.

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Vol. 57. JUNE, 1919. No. 283.

# ADDRESS TO THE IRISH CENTRE

By C. H. Wordingham, C.B.E., President.

(*Address delivered at* Dublin 19 *May, and at* Belfast 20 *May*, 1919.)

Gentlemen,

During the past Session I have visited the Scottish and each one of the English Territorial Centres and have greatly valued the opportunities which these visits have afforded me of being brought into personal contact with the members of our Institution in different parts of the country. I have long wished to visit Ireland and in the same way meet those members of the Institution resident in that country.

As you are aware the Dublin Local Section, or as it is now called the Irish Territorial Centre, was founded in December 1899 and it was one of the four first to be formed. A request was recently received by the Council to establish another Centre in Belfast and it seemed to me that it would be useful were I to ascertain the feeling of members on the spot in regard to the proposal so that I might be able to advise the Council in the matter. I therefore proposed that I should visit Ireland for this purpose the opportunity appearing to me to be a very suitable one for me to gratify the wish that I have just mentioned.

Quite recently the Institution has adopted the policy of forming Sub-Centres to deal with those parts of an area which cannot conveniently be served from the main Centre. Whether a new Centre or a Sub-Centre is established depends largely upon the number of members who would be available to support the new focus of activity and it may well be that the most suitable course would be to form a Sub-Centre in Belfast now, altering it to a main Centre if and when the numbers belonging to it justify such a course. This however is not a matter for discussion at a public meeting like this and I will therefore proceed to the main subject of my Address.

The Electrical Industry is to-day at the parting of the ways. It has often been stated in the past that the Industry is in its infancy but all must admit that it is now adolescent and, like the common run of adolescents, it is contemplating matrimony, that is to say marriage with the State. Like all marriages this is a leap in the dark and no one can say with confidence how the match will turn out. Some hope that the State will endow the Industry with much in the way of worldly goods, others hold rather strong views on the subject of marrying for money; in any case the freedom of private enterprise will to some extent at all events be exchanged for marital control. I do not know whether the State is to be regarded as the husband or the wife but I do know that the State will wear the breeches.

Divers views may very well exist as to whether the Electrical Industry is really old enough to settle down and be told what it ought to do, living its life on certain cut and dried lines that will be imposed upon it. No more flights into the realms of fancy are to be allowed to it; uniformity is to be attained everywhere and every advance must be an advance as a whole; consequently such advance must be slow and cannot lightly be undertaken.

From the time the Industry saw the light, or perhaps I should say gave its first glimmer of it, it has had a strange fascination for the legislator. It nearly came to an untimely end in its early days and its growth has been greatly stunted by outside restrictions. Now the impression has gained ground that the best remedy to apply is a hair of the dog that bit it. Let us hope that the hair will not be long enough or strong enough to strangle it.

My remarks may seem somewhat pessimistic but I am among those who notwithstanding the possibilities of danger hope for the best. It is unquestionably a great gain for Parliament to have awakened to the supreme importance of a cheap supply of electrical energy and one must be gratified to know that the recently produced Electricity Supply Bill to amend the law with respect to the supply of electricity has

been framed largely on the lines of a Report presented to the Board of Trade by a thoroughly competent and representative committee which went to great trouble to obtain evidence from all quarters likely to be well informed on the subject which it was investigating.

Under the new legislation the powers now distributed among several Government Departments and authorities will be concentrated in a new body of men to be known as Electricity Commissioners. These will be not more than five in number and some or all of them will be men of high technical attainments thoroughly versed in the problems which will concern them in carrying out their duties. They will be furnished with a staff of inspectors, officers and servants to enable them to carry out their functions with thoroughness and despatch. In them will be vested the exercise of the powers and duties under the Electric Lighting Acts at present resting with the Board of Trade and they will have very wide additional powers enabling them either by themselves or through other parties to conduct experiments and take other action with a view to improving the methods of electric supply and generally develop the Industry.

One of the main features of the new Bill is the setting up by the Electricity Commissioners of District Electricity Boards. These Boards will have as members representatives of Local Authorities, Companies and persons who are authorised Undertakers within the district for which the Board is formed and in addition there will be representatives of labour and of large consumers of electricity.

The appointment of the Chairman of the District Board lies with the Electricity Commissioners and they determine the grouping of the various areas under the District Boards and may alter the boundaries of any district from time to time.

The District Electricity Boards when constituted are charged with the duty of providing or securing the provision of a cheap and abundant supply of electricity within their district and they are invested with powers to acquire generating stations, to acquire or use main transmission lines, themselves to construct such generating stations and lines and further they may acquire undertakings or parts of undertakings of authorised distributors and Power Companies and in everything they do they are to comply with the directions of the Electricity Commissioners.

As a consequence of the establishment of a District Electricity Board all generating stations at the time of its formation which exist within its district other than private generating stations, and also such main transmission lines as may be specified, become vested in the Board subject to payment being made by the Board, but if a station is so small or so situated or equipped that it could not be conveniently used by the Board the Board may be exempted from any obligation to purchase it. It is not quite clear what will then happen to the unfortunate little station which is unwanted except that an opportunity will be given for a respectful hearing of its despairing wail.

The way in which the price of a generating station or main transmission line is to be arrived at is carefully set out in the Bill and is free from a defect in the original Report of the Committee to the Board of Trade inasmuch as it does not place at a disadvantage those undertakings which have made proper provision for depreciation as compared with those that have not. The District Board may also by agreement with the owners acquire private generating stations which they may think desirable.

An interesting condition is attached to these compulsory powers inasmuch as the Board has to undertake to supply the dispossessed authority with energy in quantities not less abundant and at prices not less favourable than would have obtained had they continued in possession of their property and (this is very important) carried out improvements which they were at the time contemplating. This proviso is very fair but one can see possibilities of a good many tussles in connection with it.

The Electricity Commissioners are given power to prevent anyone except a District Electricity Board establishing a new or extending an existing generating station without their consent but this does not apply to private generating stations; the owners of these merely have to obtain approval from the Commissioners as to the type of current, frequency and pressure to be used and if they are generating on a large scale they may have to supply any surplus electricity generated in their station to the District Board.

Power is also given to the District Board to supply energy within their district but in any area for which there are authorised distributors they must obtain the consent of such distributors except in regard to the supply for railways, tramways, canals or inland navigation or for the purposes of traction or haulage including the lighting of vehicles and vessels used therefor.

The Boards are given certain subsidiary powers such, for example, as the right to abstract water from rivers and canals under certain conditions; they may make arrangements for the utilisation of water power, waste heat and other available forms of energy and they may sell generating stations and other property no longer required for the purposes of their undertaking.

The Boards must either exercise their power themselves or if authorised by the Electricity Commissioners may do so through any authorised Undertakers or through a Company established for the purpose and they may lease their undertaking if they think fit, always subject to the approval of the Electricity Commissioners.

I am not attempting to do more than give the salient points in connection with these District Boards but from what I have said it will be fully evident to you that they will be invested with very wide powers and that where established the whole of the electricity supply in the future will be in their hands.

An important point to which I should make reference is one which concerns nearly many of our members; I refer to the compensation for those officers or servants of the transferred undertakings who have suffered loss of employment or diminution of salary or wages by the transference. The payment of such compensation is not permissive but is mandatory and this is a most

important improvement on the recommendations of the Report on which the Bill is founded.

The second portion of the Bill deals with what are called Transitory Provisions and some of these are very important.

The Board of Trade may after consultation with the Electricity Commissioners construct generating stations and transmission lines and generally exercise the powers of a District Electricity Board before such Board is formed for a given district and for two years after its formation. In order to enable the Board of Trade to act in this manner the Treasury may issue to the Board out of the Consolidated Fund of the United Kingdom any sums not exceeding in the aggregate twenty million pounds for the construction of works, the acquisition of land or for working capital on such terms as the Treasury may think fit and the Treasury may borrow the money for this purpose by means of the issue of Exchequer Bonds. The Board of Trade is under obligation to charge such prices when exercising these powers as shall be sufficient to cover their expenditure on income account including interest and sinking fund charges in respect of the advance with such margin as the Board may think fit.

Another section of the Transitory Provisions relates to the linking up of existing systems and generally to the consolidation of existing undertakings pending the establishment of the Boards but in all things the approval of the Electricity Commissioners must be obtained.

Next follow in the Bill amendments of Electric Lighting Acts enabling the powers of the Local Government Board, the Secretary for Scotland and the London County Council to be transferred to the Electricity Commissioners. The consent of local authorities to the erection of overhead wires is dispensed with though the local authority shall have an opportunity of being heard. Important powers in regard to wayleaves are given to the District Boards and to authorised undertakers and the Boards are invested with the power to let on hire electric lines, fittings, apparatus and appliances for lighting, heating and motive power and all other purposes for which electricity can or may be used. This is a most important right the absence of which has pressed very hardly on local authorities.

The prices to be charged by the District Boards are to be subject to the approval of the Electricity Commissioners and they are to be so fixed that the undertaking is not conducted at a loss. The prices are to be regulated with a view to securing to the consumer the benefit of any reduction in the cost of generation. The accounts statistics and returns of the Boards and authorised undertakings are to be furnished to the Commissioners in such form and manner as they may direct.

I may here call attention to a fallacy underlying this and an earlier portion of the Bill, viz.: the assumption that in order to make a profit you have only to raise the price to the consumer. All experience goes to show that this is far from being true, on the contrary, most often the lowering of the price brings about the desired effect.

A word of warning, addressed rather to the public at large than to my technical hearers may be uttered against extravagant hopes as to the extent of the reduction in price to the consumer that may be anticipated. It must not be forgotten that the saving expected is to be made on generation only and that the distribution charges will remain practically unaltered; hence the percentage saving made is effected on a fraction and not on the whole cost and the price to the consumer will therefore be much higher than that commonly spoken of in connection with the cost of generation. A notable feature of the future, however, will probably be a great reduction in the discrepancy between the prices charged in different, and often adjacent, districts.

Specific directions are given in the Bill as to the way in which the finance of the District Board is to be conducted and the whole is to be under the supervision of the Commissioners whose auditors will audit the accounts. It is also incumbent upon the Board to supply to the Commissioners a report of their proceedings during each year.

The Boards are given powers to borrow money for the purchase of generating stations or transmission lines and of any undertaking or part of an undertaking which they may acquire and indeed for any payment for work the cost of which ought in the opinion of the Commissioners to be spread over a term of years including—and this is a most important provision—the payment of interest on money borrowed for capital expenditure whilst the expenditure remains unremunerative; during the first three years after it is established the Board may also subject to the consent of the Commissioners borrow money for working capital. All money borrowed in this manner and the interest thereon may be charged on the undertaking and the Board's revenues or on any specific property forming part of the undertaking the period of repayment being in the discretion of the Commissioners.

Authorised undertakers whose area of supply is wholly or partly within the district of any Board and an intending consumer may lend money to the Board, subscribe for securities issued by it, guarantee the payment of interest on money borrowed by the Board and give it financial assistance in any other form subject to the consent of the Local Government Board in the case of the Council of a County Borough or County District.

Over and above the powers given to the Electricity Commissioners to lend money provided by the Treasury for the construction or purchase of works the Electricity Commissioners are empowered to lend sums aggregating twenty-five million pounds to District Electricity Boards if they are satisfied that they cannot otherwise raise the money on reasonable terms. Money issued in this way is to come from a special fund in the charge of the Commissioners to be called the Electricity Loans Fund and all funds received by the Commissioners on account of interest and repayment of the loans are to be carried to this fund.

The money required for carrying out these provisions is to be derived by Electricity Stock issued by the Commissioners bearing interest at such rate as they with the consent of the Treasury may determine. The interest on this Stock is to be charged on the Electricity

Loans Fund and is to be guaranteed by the Treasury who for fulfilling their guarantee shall charge the sums required on the Consolidated Fund of the United Kingdom.

The whole of the cost of the Electricity Commissioners' department including the salaries, remuneration, pensions and gratuities of the Commissioners, their secretary, officers and servants and all expenses incurred by them are to be paid by the Electrical Industry. The Commissioners are to apportion the amount by which their estimated expenses exceed their estimated receipts amongst the several District Boards in proportion to their gross receipts in the preceding year and the Boards are to pay the sums apportioned to them as a contribution towards the expenses of the Commissioners. The money required during the first five years may be advanced by Parliament but must eventually be returned by equal annual instalments during the next three succeeding years.

The Bill concludes with a number of general clauses among which may be mentioned the giving of power to the Commissioners to hold inquiries and to take evidence on oath; the power to make rules in regard to applications and other proceedings before the Commissioners and other matters; the power to make special orders which special orders do not take effect unless and until confirmed by the Board of Trade. The Bill concludes with definitions and particulars of its application to Scotland and Ireland with a clause giving power to transfer the powers and duties of the Board of Trade under the Bill to the Ministry of Ways and Communications in the event of that being established.

From the brief paraphrase of the Bill which I have just given it will be evident that a radical change is about to be made in the conditions governing electric supply in Great Britain. The concentration of the legislative control in the hands of a single body the members of which will presumably be chiefly technical experts highly skilled in the problems with which they have to deal is a gain the importance of which it is impossible to overestimate. The powers conferred upon these Commissioners are such as will enable them to control the design of the generating stations and transmission and distribution systems which are to be put in in future and gradually to eliminate those which do not conform with the general scheme. The day of the small and inefficient undertaking is about to pass and we may look forward to electrical generation on the Grand Scale with stations on sites enabling generation to be carried out on the most economical lines. The main danger to be guarded against is a tendency to carry uniformity of system too far or to ride to death the idea of very large stations or as they have been not too happily named "super-stations." There are still areas in which it may pay better to put down a small isolated station on a site not ideal rather than to insist upon the supply being taken from an economical generating station unduly far off. If the right men are chosen however they will realise this and will not be unduly autocratic nor too closely wedded to preconceived ideas.

The powers given to the Commissioners for the carrying out of investigations with a view to improvement in practice are also of great value. It is true that the colossal scale on which any alteration in practice that may be determined on will have to be made will tend to deter the Commissioners from launching out into other than well tried improvements and this may mean a certain amount of backwardness as compared with experiments made by individual enterprise but it is to be hoped that means of avoiding this danger may be found.

The vesting of the carrying out of the supply in the hands of a District Board is an experiment which may well give rise to a good deal of speculation as to the results. There are those who hold that municipal enterprise has been attended with excellent results and that management by a committee is entirely practicable. Others again hold that only private enterprise in which the control is vested in a few directors of great commerical and often of technical experience can give the best results. The District Board would probably function very much in the same way as a municipal committee but it would probably be larger than an ordinary electricity committee of a Corporation and the introduction of large consumers and of labour may tend to weight being given to considerations which are very far removed from those making for the technical and commercial success of the undertaking. Like all constitutions the success or failure of the scheme must depend ultimately upon the individuals in whom the administration is vested and one can only hope that the organisation proposed will be for the good of the Industry.

The Bill whatever its defects, if defects there be, is clearly an honest attempt to improve materially the position of the electric supply industry in this country: it has been framed on advice given after the fullest consultation with members of the Industry itself and its actual drafting has been with the aid of the highest technical advice obtainable. More than this we cannot ask and it rests with every member of the Industry to do his utmost to make the scheme work and the Industry thrive.

There can be little doubt that with the abundant supply of energy which should shortly be available the applications of electricity to industrial purposes and everyday domestic life will be largely augmented and a great stimulus should be given to electric manufactures of all kinds.

An important feature of the developments contemplated is the utilisation of sources of energy now running to waste and the pressing into service of all available energy. Attention has been directed chiefly to the utilisation of blast furnace gas and this will no doubt be one of the principal sources of waste energy but we must not overlook the water power which now runs to waste and which though not concentrated in any great quantity at any one place is in the aggregate of considerable magnitude. Already a scheme has been prepared for utilising the power inherent in the water which falls on Dartmoor and there should be great opportunities for development in this direction in Ireland. The water power problem is greatly facilitated when worked in conjunction with large steam driven stations and all sources feed into a common supply system. In Ireland there are also great possibilities

in the direction of the utilisation of peat for fuel but into this I cannot enter here.

In the great development to which we are looking forward we may well ask what part is the Institution of Electrical Engineers going to play. That Institution, originally founded as the Society of Telegraph Engineers in 1871, has grown with the growth of the Industry and after passing through successive stages is now the Institution of Electrical Engineers with a membership of between seven and eight thousand. Already it has done a large amount of useful work for the Industry and it is unquestionably a living force. If however it is to effect anything like the amount of good of which it is capable it is essential that it should be given wider and more effectual powers. Until a comparatively recent period its activities were directed chiefly towards the reading of papers on scientific and technical subjects, the organisation of discussions on scientific and engineering matters and the provision of library facilities for its members. Of late however the Institution has taken a much larger hand in industrial matters and while not actually entering the commercial field it has afforded facilities to organisations whose objects are chiefly commercial for meeting under its auspices jointly with its own representatives and in some cases it has been instrumental in the formation of new Associations having commercial objects and the protection of the material interests of those constituting its membership.

In my judgment it is absolutely essential if the Electrical Industry is to rise to the heights of which it is capable that there should be one and only one representative body able to speak in the name of the entire industry. Such a body could readily be formed by the expansion and development of the Institution as we now know it. I have recently described in outline a scheme in accordance with which these objects could I think conveniently and practicably be effected but time does not admit of my entering into the matter here. I hope however that all members of the Institution will do me the honour of reading the Address which is published in the current number of the Institution *Journal* * and that the Irish Section will give an opportunity to its members of discussing at one of their meetings the proposals which I have outlined.

Briefly I proposed that all the existing Associations and some new ones should be knit together by sending representatives to a Grand Council of the Institution and that this Council should speak for the entire industry to Government and all extraneous bodies. Questions affecting a particular branch of the Industry would be referred to the body set up to deal with that branch and the Grand Council would act on the advice of the representatives from that specialised body.

Through its Professional Council the Institution would under the Charter which I suggest be able to determine the qualifications constituting a man an electrical engineer; it would hold examinations and grant diplomas and in fact do for the Electrical Industry what has already been done for the Medical Profession and for the Law. In other words a man not having the Institution diploma would not be entitled to call himself an electrical engineer. The professional body would take an active part in engineering education and it would develop greatly the usefulness of the library. It would provide a service whereby any member could obtain a full account of all that was known on any given subject up to the present moment and would be able to get abstracts and translations of articles dealing with matters in which he was interested.

All interests would be provided for under separate sectional committees on the lines which have recently been started in our present Institution; there would thus be no need to form new Societies when some branch such as Wireless came into being. The management of each branch would be by a committee under the Professional Council which would have charge of the affairs of the section and do all that could be done by a separate society without the attendant expense of additional subscriptions entailed by the unnecessary multiplication of staffs, offices and organisations.

I have only been able in the time at my disposal to give an extremely brief sketch of the future whether in regard to the prospects of the Industry or of the part to be played by the Institution but I hope I have said enough to show that great developments may be confidently anticipated and that the community at large has much to hope for and to gain by the prosperity of the Electrical Industry.

* *Journal I.E.E.*, 1919, vol. 57, p. 338.

# THE GENERAL PRINCIPLES OF THE DEVELOPMENT AND STORAGE OF WATER FOR ELECTRICAL PURPOSES.

By J. W. Meares, Member.

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## Introductory.

The extensive use of hydro-electric development is a noticeable feature of most countries which possess natural water power, especially where there is concurrently an absence of coal-fields, but the general principles underlying such developments are very little understood outside the ranks of those directly interested. Great Britain has vast quantities of coal and very little developed water power, with the result that most of her engineers never have occasion to study water power. But many of her sons will inevitably emigrate after the war, and the engineers among them will find themselves handicapped if they are unable to deal with problems of this nature.

There is not a great deal of literature on the subject; papers read before learned societies consist for the most part of descriptions of particular installations, while treatises dealing with this branch of engineering are largely concerned with details of electrical transmission and other cognate matters. It is proposed in this paper to examine the subject purely from the point of view of delivering, and continuing to deliver, water to a prime mover, from which point onwards the problem does not greatly differ from that of the ordinary central station or group of interlinked stations. The last paper read before the Institution on the general subject of water power was that by Mr. A. Steiger in 1896,* and it was concerned mainly with types of low-fall turbines. In the present paper mechanical design is not touched upon; the collection, storage, and delivery of water on high, medium, and low falls is the whole scope of the contribution.

* A. Steiger: "The utilization of water power, especially with a small fall," *Journal I.E.E.*, 1896, vol. 25, p. 521.

## The Conditions Requisite for Water Power; Classification According to Head.

A country may have vast rivers and yet very little water power capable of economic development. For, unless a natural fall is ready to hand, an artificial one must be created. If a river bed has a slope of only a few inches to the mile, as is the case with many large rivers in flat countries, the power that exists in the sluggish flow is incapable of utilization except possibly by very small undershot waterwheels. The difference of level at different seasons would alone put any such proposals out of court, as would also the cost.

As the power obtainable in any case is proportional to the product of the weight of water multiplied by the height of fall, it follows that either a large volume of water flowing under a small head or a small volume flowing under a high head will serve; the majority of installations actually utilize a medium volume flowing under a moderate head. The problems of low, medium, and high heads differ considerably, however, and each may be dealt with in various ways. There is no exact line of demarcation between the three stages, but, generally speaking, low heads may be taken to be those involving the use of pressure or reaction turbines, often submerged, with suction or draft tubes connecting the outlet with the tail race, from about 3 feet as a practical limit up to 80 or 100 feet. High heads are such as are dealt with by the jet impulse type of wheel exemplified by the Pelton wheel, from a possible 5,000 feet or so down to 300 or 400 feet. Between these two extremes lie the medium falls, using impulse turbines of various types according to the head. In America this type of wheel is little used and jet impulse wheels are mostly used. For ready reference the theoretical spouting velocity $[V=\sqrt{(2gH)}]$ and static pressure ($P=0{\cdot}433$ lb. per square inch per foot of head) are given in tabular form for various heads. The actual issuing velocity will be slightly less, about 3 to 4 per cent, on account of the frictional resistance of the edges of the orifice; while the pressure at the nozzle will be lower normally by the loss of head in the system and may be greatly increased by water hammer if the flow is suddenly arrested.

TABLE 1.

| Head in feet | Spouting velocity; feet per second | Static pressure; lb. per sq. in. |
|---|---|---|
| 3 | 13·9 | 1·30 |
| 10 | 25·3 | 4·33 |
| 50 | 56·6 | 21·6 |
| 100 | 80 | 43·3 |
| 500 | 179 | 216 |
| 1,000 | 253 | 433 |
| 3,000 | 438 | 1,299 |

The gross head in high and medium falls is the vertical difference in height between the point of application to the wheel and the water-level at the pipe intake; while for low heads the difference between the level of the head and tail waters must be taken. The net head is the gross head diminished by the loss in the connecting system.

### FLOW AND STORAGE.

The above classification according to head may be further subdivided in considering possible sources of water power, for just as the head may be natural or artificial so may the flow of water. With rivers and canals the natural flow is the prime feature, and even with mountain streams it is of great importance; but in every case, given suitable conditions, storage may be an almost equally important factor. In a project recently described * natural flow into the reservoirs only operates for a few weeks during the monsoon, and for the greater part of the year the maintenance of supply is dependent solely on storage; more frequently flow and storage are combined, and the conditions resulting from each category are dealt with in this paper.

### EFFICIENCY OF HYDRO-ELECTRIC PLANT.

At the most economical load the efficiency of various types of hydraulic turbine or wheel varies from 85 to 90 per cent in large sizes, while the corresponding overall efficiency of alternators, including excitation losses, will be from 95 to 97 per cent. Thus the overall efficiency under the most favourable conditions will vary from 81 per cent to 87 per cent. In practical working, however, the most favourable conditions are not maintained; the plant will not all be running at full load and there will be some appreciable additional loss in all systems having any length of pipe—a loss increasing with time and incrustation. In low-head plants eddies also affect the efficiency. For practical industrial purposes it will be sufficient to assume the overall commercial efficiency, E, of the plant M to be as in Table 2.

TABLE 2.

| | | |
|---|---|---|
| For 500 kw. | .. .. .. | 71 per cent |
| ,, 1,000 kw. | .. .. .. | 76 ,, |
| ,, 1,500 ,, | .. .. .. | 78 ,, |
| ,, 2,000 ,, | .. .. .. | 80 ,, |
| ,, 3,000 ,, and over | .. .. | 82 ,, |

* A. DICKINSON: "The Bombay hydro-electric scheme," *Journal I.E.E.*, 1915, vol. 53, p. 693.

Using the convenient irrigation unit of a "cusec" for a flow of a cubic foot of water per second (termed a foot-second in America), we then have:

$$\text{E.H.P. output} = \frac{\text{cusecs} \times 62{\cdot}4 \times \text{gross head in feet}}{550} \times \frac{E}{100}.$$

As, however, we are more concerned with kilowatts than with electrical horse-power it will be convenient to use a direct conversion factor and to avoid decimals of no real significance, as follows:—

TABLE 3.

| | | | |
|---|---|---|---|
| For 500 kw. | = cusecs × gross head | × 0·062 |
| ,, 1,000 ,, | = ,, ,, ,, | × 0·064 |
| ,, 1,500 ,, | = ,, ,, ,, | × 0·066 |
| ,, 2,000 ,, | = ,, ,, ,, | × 0·068 |
| ,, 3,000 ,, or over | = ,, ,, ,, | × 0·070 |

For rough purposes indeed it is quite sufficient to take kilowatts = cusecs ×.feet/15, or B.H.P. of turbine = cusecs × feet/11 for mechanical power as reliable mean figures, except for small installations where the divisor will be higher.

From these data the curves in Fig. 1 have been drawn, giving the kilowatts which will be generated from any flow under any head within practicable limits. Thus

| | | | | |
|---|---|---|---|---|
| 6,500 cusecs on | 3·5 ft. head | will give | 1,500 kw. |
| 650 ,, | 35 ,, | ,, | ,, |
| 65 ,, | 350 ,, | ,, | ,, |
| 6·5 ,, | 3,500 ,, | ,, | ,, |

Interpolation will find intermediate heads between the curves near enough for all practical purposes.

Before proceeding further it is necessary to point out that even in the most favourable circumstances the water flowing through the turbines is only a proportion—and a very variable proportion—of that which is precipitated on the catchment area. It is therefore necessary to refer generally to the factors of rainfall, run-off, evaporation, percolation, and other matters which affect the problem, especially where storage is an essential part of a project.

The author is at present engaged upon the survey of the water-power possibilities of India and Burma, which has been placed under the direction of Mr. G. T. Barlow, C.I.E., late Chief Engineer for Irrigation in the United Provinces; and as the East Indies are for the most part subject only to seasonal monsoon rainfall, the conditions there are somewhat special with regard to these disturbing factors, although much that follows will be common to all countries.

### RAINFALL AND RUN-OFF.

If the rainfall over a particular catchment area in any period is actually known, and the stream flowing from it can be gauged, the percentage of run-off can at once be calculated for the conditions obtaining during that period; but the rain-gauge readings must be taken at a number of points—the more the better—in the catchment in order to ascertain the actual

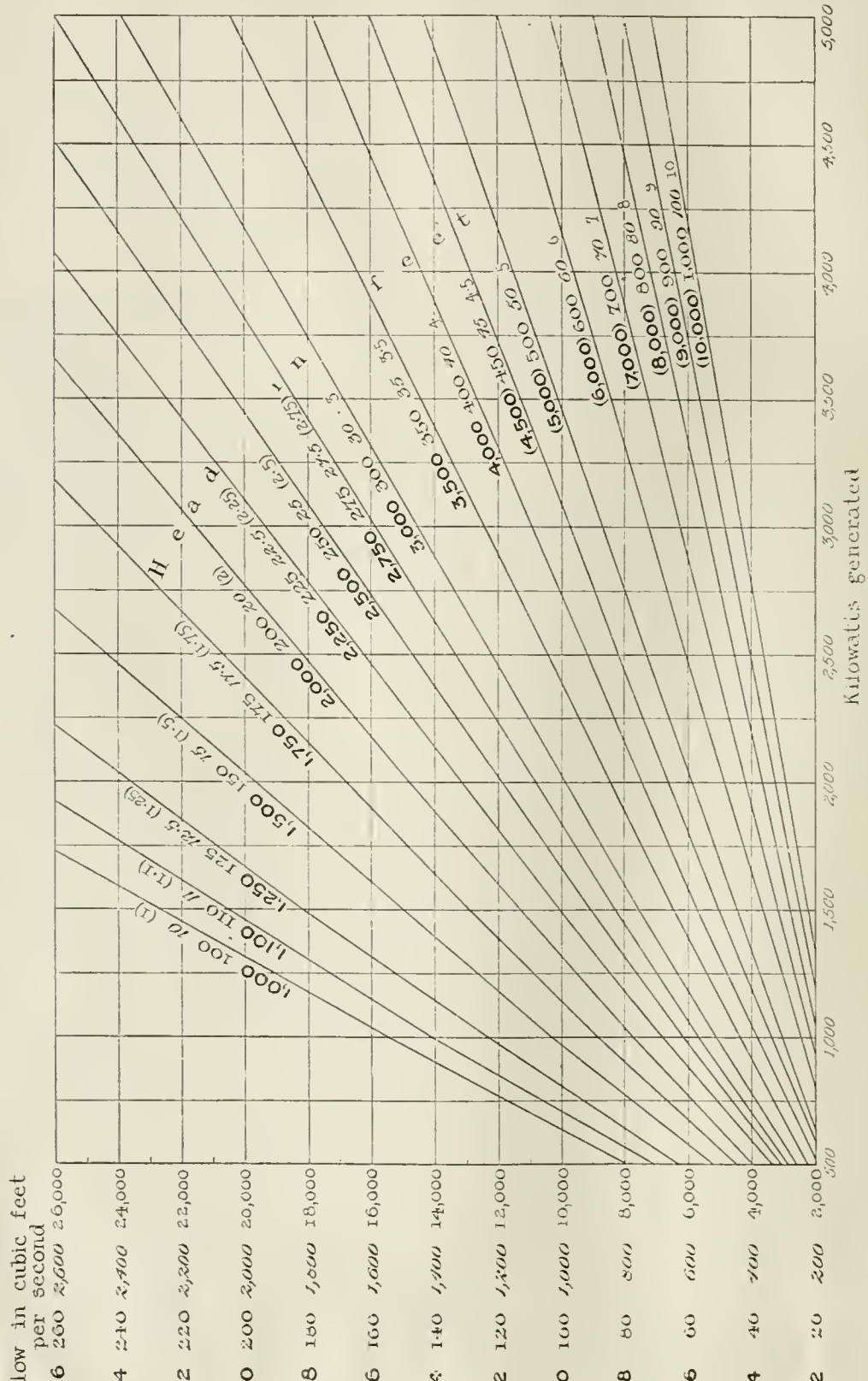



FIG. 1.—Number of kilowatts obtainable from any flow of water under any head from 3 feet upwards.

The figures of flow correspond from left to right with those of head, as shown by the different type employed.

amount of precipitation. In addition to the very large differences of average rainfall in different countries and localities, and the great variations from the average in particular years, the distribution of the fall, month by month and day by day, must be taken into account. Unless enormous reservoirs can be constructed, the greater part of the rainfall in a monsoon area must inevitably flow to the sea unused either for power or for irrigation.

To take an example, the "Preliminary Report of the Water Power Committee of the Conjoint Board of Scientific Societies" states that "The catchment area drained by the upper reaches of the rivers (i.e. the Irrawaddy and Salween) is about 80,000 square miles, and assuming it possible to utilize one-fifth of the discharge (based on 100 inches of rainfall) over a head of 500 feet, this would give a potential seven million horse-power. Actually much the greater part of the discharge is in the monsoon months and by no possibility capable of utilization, and it is doubtful if a head of even 100 feet could be developed at any places within reach of civilization. Too much water is almost as great a disadvantage as too little, owing to the extreme difficulty of getting rid of it. These rivers could, no doubt, be harnessed, at enormous cost, for perhaps 500,000 h.p. if there were not many far more favourable sites among their tributaries.

Minimum discharges on small catchments may vary four- or five-fold in different years, and are extremely difficult to calculate; a long series of rainfall averages will, however, indicate to some extent the relation between the unknown discharge of an exceptionally dry year and the known discharge of a particular year. Intelligent guesswork of this nature presupposes knowledge of local conditions and long experience.

Formulæ for calculating the maximum run-off from a catchment have been devised by many engineers,* but they all employ coefficients which it is impossible to ascertain without a comprehensive study of the nature of the area and the rainfall. It may, however, be accepted that a study of the daily rainfall observations over a period of 30 years will give a fairly accurate idea of the conditions which are likely to occur in future, and if different percentages of run-off are assumed for light, medium, and heavy falls, depending on the nature of the catchment, a fairly accurate forecast can be made.

As a practical example of the method, the following empirical table has been tentatively adopted in the United Provinces (India). The author's acknowledgments are due to Mr. G. T. Barlow, C.I.E., Chief Engineer, for permission to publish it, as well as for much of the information in this section of the paper.

*Light falls* under $\frac{1}{2}$ inch in 24 hours should be entirely omitted unless continuous for several days; falls from $\frac{1}{2}$ inch to 1 inch in 24 hours should be omitted if there has been no fall before or after. Falls from 1 inch to $1\frac{1}{2}$ inches, when not followed or preceded by similar or greater amounts, are considered to be light.

*Medium falls* are those from 1 inch to $1\frac{1}{2}$ inches when followed or preceded by any but light falls; also all falls from $1\frac{1}{2}$ inches to 3 inches.

* R. B. Buckley, C.S.I.: "Irrigation Pocket-book," 2nd edition, p. 192.

*Heavy falls* are those over 3 inches, or continuous falls over 2 inches a day; also all falls of an intensity of 2 inches an hour or over.

Table 4.

Showing Percentage Run-off Assumed.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| Light falls .. | 1 | 3 | 5 | 10 | 15 |
| Medium falls .. | 10 | 15 | 20 | 25 | 33 |
| Heavy falls .. | 20 | 33 | 40 | 55 | 70 |

A = flat, cultivated and black cotton soil catchment.
B = flat, partly cultivated and stiff soils.
C = average catchment.
D = hills and plains with little cultivation.
E = very hilly, steep and rocky with very little cultivation.

Obviously such a classification would be unsuitable in most parts of Europe or America, but it brings out clearly the nature of the variations to be met with in a particular locality. A thunderstorm with a rainfall of $\frac{3}{4}$ inch in 20 minutes would give double or treble the run-off of the same fall spread over a day; but nearly all rainfall observations give the daily fall and not the hourly intensity. The classification of daily rainfall over a long period sounds a serious proposition, but is really a matter of clerical labour only. Owing to the disturbing effect of hills, etc., isolated observations at one point of a catchment may be very misleading; hence the necessity of many gauging stations wherever possible. Rainfall contour maps are only useful as a general guide, unless prepared on a large scale from observations made for the purpose.

In India the rainfall varies in different localities from 450 to a few inches, mostly precipitated in about 4 months, while catchment areas vary in nature from waste sand to steep rocky country. In some parts the ground is highly cultivated or covered with dense forest, while in others there is hardly any soil or vegetation; the soil itself varies from the stiffest clay to the lightest loam or sand. With these variables it is easy to realize that the run-off must vary greatly and is incapable of treatment by any general formula of universal applicability.

### Evaporation and Percolation.

Apart from the fact that a considerable percentage of rainfall is evaporated before it reaches the big rivers, as well as from their surface, the question of evaporation arises wherever long canals or large storage reservoirs are employed. The actual amount of evaporation varies so greatly that no general figure would be of the slightest value; in India it may be as much as 6 feet in the year, but for details of many known reser-

voirs Buckley's "Irrigation Pocket-book" may be referred to. Percolation and absorption also account for no small amount of the water entering a canal in natural ground or a reservoir, but the loss must obviously be determined in each case as it arises. Owing therefore to these various unknown factors, the data given in relation to storage in this paper, except where otherwise mentioned, do not take into account the losses due to them.

The following figures are worth remembering in connection with water-power projects involving storage: $31\frac{1}{2}$ million cubic feet of water will give 1 cusec throughout a year; or, taking losses into consideration, about 35 million cubic feet.

A square mile submerged to 1 foot gives about $27\frac{3}{4}$ million cubic feet, and an acre-foot about 43,000 cubic feet. The use of billions (as in the U.S.A. and Canada) is open to objection as it has at least two different meanings. The original term in astronomy connotes a million millions, and is still current, whereas it here stands for thousands of millions only.

### Reservoirs.

While in most countries the rivers and streams are perennial, this is not generally the case in India where many imposing streams dry up entirely before the monsoon; furthermore, practically the whole hot-weather discharge is taken up for irrigation in many other instances, although it fortunately happens that the headworks of the irrigation canals are generally taken off at a point below that which would be most suitable for power purposes. Where storage can be developed on a large scale it may go far towards balancing the deficiency of flow in the dry season, whether for irrigation or for power or for both.

The best sites for the dam containing the reservoir and for the escape for surplussing the excess flood waters require careful consideration. The ideal site for a reservoir is where a stream with a good catchment area runs through a fan-shaped valley with flat longitudinal and transverse sections. The soil, cultivation, habitations, and other works must also be considered with regard to both the location and the economic height to which it is advisable to store water. The dam should evidently be placed where the valley contracts and, if possible, where there is good solid rock to found upon. Trial pits alone are not sufficient evidence and the whole alignment should be trenched.

Where the catchment is large, the valley cultivated, and the flood water escaped over the dam itself, it is generally more economical to build the dam where the best rock for the foundations is found, rather than at the narrowest point of the valley.

Excess flood water can be escaped either over the top of a masonry dam, or by undersluicing, or by a separate flank or saddle escape. In all cases it is necessary to have solid rock or masonry, as otherwise the high cost of the protective works is likely to ruin the project. Flank or saddle escapes are generally used when the main dam, whether of masonry or of earth, is founded on soft rock or earth. Occasionally when the catchment area is small, and rock foundations cannot be obtained, it is advisable to construct the dam to such a height that the whole of the run-off may be stored.

The economic height of the dam and the line to which storage water is to be collected depend upon:

(*a*) The requirements for power or irrigation, or both.

(*b*) The catchment area available for storage: it is frequently possible either to add extra catchment areas at a small cost, where water is deficient, or to divert a portion of the area to another drainage when it is in excess of the requirements and there are difficulties about the escape.

(*c*) The rainfall on and the actual run-off from the catchment.

(*d*) The nature of the submerged area, where an extra foot or two of height may involve on the one hand the submergence of valuable property or, on the other hand, may mean an extra 50 per cent to 100 per cent of storage capacity.

(*e*) The nature of the seasons; for in some places the annual rainfall is very variable in both amount and intensity, so that the run-off may vary from zero to nearly 100 per cent of the rainfall. In such cases provision must be made for the carrying over of the water from the good to the bad years. This is especially necessary in all reservoirs used for power or sanitary purposes and may not always be possible in irrigation projects.

### Water Storage and Power.

Whether water is stored on a large scale behind dams, or on a small scale in reservoirs, there are many variable factors in addition to the efficiency of the plant; the original capacity is seldom known with exactness and varies according to the amount of silt deposited, or the date of the last cleaning-out in the case of reservoirs capable of such treatment. It will be sufficient therefore to assume here an overall efficiency in the plant of 76 per cent, giving straight-line "curves." With this efficiency 1,000 kw. requires a flow of 15·54 cusecs under 1,000 ft. head, or 15,540 cusec-feet under any other head.

With the assumed head of 1,000 feet this flow of $15\frac{1}{2}$ cusecs represents (in round figures and exclusive of evaporation and percolation) $1\frac{1}{3}$ million cubic feet a day; 41 million cubic feet a month; 490 million cubic feet a year; to maintain 1,000 kw. continuously in each case. For any other head the storage will vary in inverse proportion, while for any other value in kilowatts of continuous output it will vary in direct proportion.

Now 1 kw. for a year represents 8,760 B.O.T. units, so the above 1,000 kw.-years give $8\frac{3}{4}$ million units on the assumption of 100 per cent load factor. The amount of storage is therefore directly proportional to the units generated, whatever the load factor may be; for if the load factor is 50 per cent it follows that 2,000 kw. of plant can actually be maintained by the above quantities on the assumed head, while the output in units will be unaltered. The accompanying

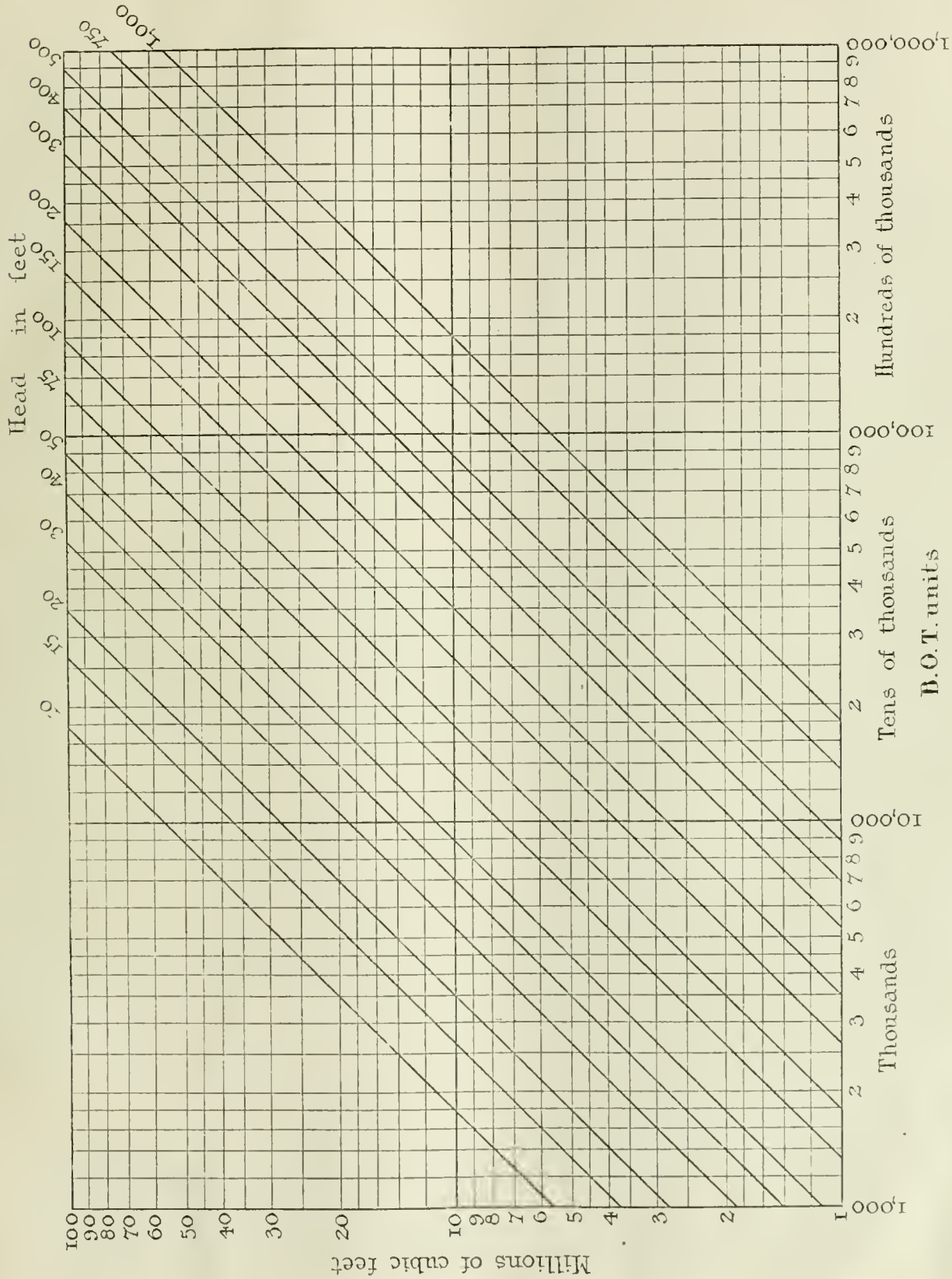

Millions of cubic feet
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
Thousands
1,000 2 3 4 5 6 7 8 9
Tens of thousands
10,000 2 3 4 5 6 7 8 9
Hundreds of thousands
100,000 2 3 4 5 6 7 8 9
1,000,000
B.O.T. units
Head in feet
0 15 20 30 40 50 75 100 125 150 200 300 400 500
1,000
750

FIG. 2.

logarithmic diagram (Fig. 2) illustrates the relation of storage to B.O.T. units for any head. Thus for 2,000 ft. head the 200 ft. curve may be used and either the units multiplied by 10 or the storage divided by 10; and so forth. As before, interpolation (for which any slide rule will serve if laid so that 1 and 10 correspond on the diagonals) will give intermediate heads; and if the cubic feet be multiplied or divided by 10, 100, etc., the ordinates (units) similarly treated will correspond. A scale of kilowatt-years on 100 per cent load factor can be laid off by taking 1 kw.-year at 8,760 units, 10 kw.-years at 87,600 units, and so forth.

By way of illustration, Mr. Dickinson's paper already quoted gives the details of three lakes on the Bombay (Tata) hydro-electric scheme, containing respectively 361, 2,560, and 6,963 million cubic feet of water. These reservoirs are at considerable distances from the forebay supplying the pipes, and the static head is 1,725 feet. From the diagram it will be seen that as 31·5 million cubic feet give 100,000 units on 175 ft. head, or 1 million on 1,750 ft. head, the three lakes will give about 11½, 80, and 220 million units respectively, subject to correction for evaporation and losses. On the basis of 100 per cent load factor they would supply about 1,300, 9,000, and 25,000 kw.-years respectively. The actual load factor of the plant on the last returns available was 30 per cent, so the plant capable of being served under working conditions is about three times the above; and in fact the full reserve would allow a considerable defect in the monsoon rainfall without endangering continuity. The largest reservoir is not yet completed.

The height of the water in the lakes affords therefore an immediate gauge of the reserve in hand. In the Chief Engineer's office is a curve showing the actual reserve for every foot of water behind the dams. Thus the surface area of the Shirawta lake when full is 3,174 acres, so that the first foot of depth is equivalent to 138 million cubic feet of water or 4½ million units.

### Limitations of Storage According to Head.

The function of water storage is two-fold: on the one hand, increase of power throughout the year or the dry season; on the other hand, regulation day by day. The latter may in favourable conditions also enable the size of the plant to be substantially increased. The incidence of the rainfall, the rate of evaporation, the natural possibilities of the ground, and the load factor of the plant all enter the argument. It is evident that where low heads are involved storage on the above scale of power will be impracticable. The amount of storage that will serve to give (say) 1,000 kw. for a year on 1,800 ft. head would give the same for a month on 150 feet and for a day only on 5 feet. When a high rate of charge is proposed for the use of water power it is perhaps not realized that it is gravity, not water, which is to be utilized; and that it is because water is heavy, not because it is wet, that it is valuable in transit through turbines.

### Storage on High Heads.

Within ordinary limits of capital cost, therefore, a project depending entirely on monsoon storage, with no appreciable inflow during the greater part of the year, is impracticable except on high heads. Of course the possibility of storage on the grand scale at all postulates suitable conformation and geological formation of the ground to enable a dam free from serious seepage to be constructed at reasonable cost, and this must be borne in mind in all that follows.

Where a moderate flow of water is normally available under a high head, storage on a large scale may be used to supplement the flow at seasons of low water, provided that the excess flow in flood times can be depended upon to fill the reservoir. Thus a flow of 15 cusecs under 2,000 ft. head will give 2,000 kw. continuously, or considerably more on ordinary load factors. If this flow is the minimum, it follows that much water will be running to waste at other times, in the absence of storage. Assume the average flow throughout the year to be 45 cusecs, then the excess 30 cusecs can be stored. It would amount to 950 million cubic feet in the year, but, as there would be a draw off whenever the flow diminished, only a proportion of this storage capacity would be actually required. It would suffice to give a further 4,000 kw. continuously, so the whole plant, assuming a 50 per cent load factor, could be 12,000 kw.

### Storage on Medium Heads.

In the same way where a moderate minimum flow is combined with a medium head, storage on the same large scale can be utilized to impound the excess flow within limits. If the minimum flow is equivalent to 2,000 kw., say 100 cusecs on 300 ft. head, and the average flow is 200 cusecs, it is clear that the whole of this excess could not be stored without undue expense; but a reservoir of practicable size would enable a larger plant than 2,000 kw. to be installed. If the whole of the excess rainfall were precipitated in the course of a few months the greater part of it would necessarily pass over the spillway and the amount retained would only suffice to keep a moderate-sized unit working for the remainder of the year; but if the rainfall were well distributed much more of it could be utilized. Fig. 2 will enable these two conditions to be investigated for any size of reservoir. Where rainfall is fairly regular, except for a few dry months, storage would act as a reserve to tide over the dry period with a larger plant than the minimum flow could deal with. Assume 1,000 million cubic feet of storage. Then, on 300 ft. head, this is equivalent to 5½ million kw.-hours. In the first instance this would mean an extra 800 kw. working continuously for 9 months; in the third case it would keep 2,400 kw. at work for the 3 dry months; subject in both cases to the load factor, which would allow more plant actually to be installed.

It generally comes about that on medium heads storage can only be utilized as reserve against drought, or against breakdown in the water channel where one is necessary, and not for increasing the plant capacity greatly above that maintained by the normal flow. For regulating purposes, however, it can be exceedingly useful, especially where the load factor is bad. Thus, in the case of a small plant, if the daily maximum

load over the lighting peak is 3 or 4 times the average load, and the normal minimum flow can be depended upon at the forebay—i.e. excluding the liability to serious breakdown in the flume or channel—very little storage will be of great value. Assume a minimum dry-season flow of 20 cusecs and a head of 500 feet, equivalent to 630 kw. generated. This minimum flow is then capable of generating 15,000 units per diem, if it can all be utilized. The load curve (Fig. 3), squared for convenience of demonstration, shows a peak load of 1,800 kw. for an hour, and the load factor (i.e. ratio of the area of the curve to its enclosing rectangle) is 34 per cent, so that 14,700 units are generated altogether. The dotted line shows the power which the flow can generate, while the shaded areas represent the period when excess water is being stored and drawn on respectively. Between midnight and 17 hours 5,700 units are actually generated, while the flow is capable of giving 630 × 17 or 10,700 units. Therefore 5,000/10,700 of 20 cusecs or 9·35 cusecs can be stored. This in 17 hours amounts to some 570,000 cubic feet,

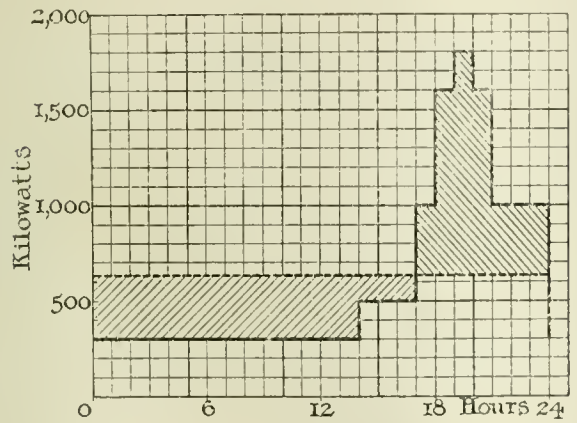



Fig. 3.—Typical load curve.

an amount which will more than serve to supply the extra 4,600 units between 17 hours and midnight. Many a small proposition has been turned down for lack of understanding this valuable application of storage. The advantage of squared paper in dealing with these questions will be evident from the load curve, where one-tenth inch square represents 100 units and also 11,400 cubic feet of water. From Fig. 2 it will be seen that this is so, as 10,000 units on this head correspond to 1,125,000 cubic feet. The slight disproportion is due to the efficiency of this small plant being taken at 74 per cent whereas the storage curves take 76 per cent.

### Storage Impracticable on Low Heads.

As a general rule large-scale storage is impracticable on low-head plants; that is to say, although there may be a considerable reserve behind a dam, either feeding directly into the turbines or further upstream, it is generally no more than suffices for regulation. The enormous volume of water required to maintain a large unit of plant for even a month would render such a proposition commercially impossible.* In rare cases only would the lie of a river allow impounding on the necessary scale, while with a canal it would never do so. As a rule, however, the flow in low-fall installations is fairly regular, so that no storage is required.

### Lay-out of Hydro-electric Schemes.

With a steam generating station the main considerations in fixing a site are facilities for condensing water and for fuel delivery and ash removal; none of these operate in the case of hydro-electric plant, which must be placed where the ground admits, and designed to suit it. Thus it may happen that a high fall cannot be developed conveniently as a single station, but can be utilized in the form of two stations in series, the tail water of the one discharging into the headworks of the next. This has been done at the two Santa Ana Creek stations at Redlands, California; and in the small development at Darjeeling, India, which the author carried out in 1896, the method has been used for subsequent extensions. Fig. 4 shows the varieties of hydraulic lay-out met with in practice, as described in the following pages.

### High-head Lay-out.

High-head schemes are necessarily located in mountainous country, and are generally fed from torrents of small volume, liable to heavy flood and consequently bringing down much mud as well as gravel and large stones. Even if the headworks have a dam it is generally necessary to have settling tanks and a forebay, in order to prevent damage to the wheels from foreign matter travelling at high velocity. In order to get the most suitable fall with as short a length of pressure pipe as possible, it is almost always necessary to carry the water along the hillside for a considerable distance in an open channel (Fig. 4 *a*), generally of artificial construction, though occasionally merely a cutting in earth. This will be dealt with subsequently, so far as the design of the canal channel or flume is concerned. The channel offers a weak link in the chain, and duplication is impossible, though occasionally two or more separate sources of supply may be tapped by different routes. To allow for fluctuations of load (apart entirely from the question of settling tanks) a forebay at the head of the pressure pipes is essential, unless water is so plentiful that an excess is always running to waste at that point. The forebay must be of such capacity that it will supply the excess water, over and above what the supply channel brings, at the time of peak load, or in the case of sudden heavy loads (e.g. short-circuits) thrown on the station. If the forebay is too small, and runs out even momentarily, air will get into the pipes and water hammer will probably follow when they refill.

Thus if the channel can deal with a steady load of 2,000 kw., and the peak load averages 2,500 kw. for 2 hours, there must be at least 1,000 kw.-hours stored in the forebay. On 1,000 ft. head this amounts to

* About 16,000 million cubic feet of water would be required to maintain only 100 kw. for a year on a 3 ft. head. This is over twice the quantity the Shirwata dam is designed to hold up. *Journal I.E.E.*, 1915, vol. 53, p. 693.

about 56,000 cubic feet. This amount, however, is of no practical use as a reserve against a temporary breakdown in the channel or at the headworks, and wherever possible a scheme of this nature should have enough storage at the pipe head to tide over at least a few hours' stoppage from such causes. For this much greater capacity is necessary, and it may not always be possible to provide it. If the ground will allow no more than a regulating forebay, a reservoir must be constructed elsewhere, and the nearer to the pipe head the better. If, however, large-scale storage by means of a dam is possible it will almost always necessarily be either upstream of the headworks or at them, and the chances of a break in the flume must be risked. Large reservoirs, constructed by means of dams, can obviously only be located where the ground offers natural facilities, i.e. at a comparatively narrow neck in a valley, which opens out above and does not rise steeply. Where comparatively small storage is required more latitude is found. In some cases of steep ground it is possible to locate the power house so near to the headworks, even with high heads, that the water can be carried in pipes the whole way, without an open channel (Fig. 4 *b*). Here the risk of breakdown is a minimum. An intermediate case between these two extremes is where the distance from reservoir or headworks to power house is considerable, but a channel cannot be constructed owing to the slope of the ground. Generally the steep fall will be at the lower end of the pipe line, and the upper reaches will fall very little. In America the usual method of dealing with such problems is to use wood stave pipes for the upper part of the pipe line, with a surge tank at the junction of these with the steel pressure pipes, where the steep fall begins (Fig. 4 *c*). The surge tank consists of a reservoir, elevated to the level of the water where it enters the stave pipes, connected by a large pipe (or separate pipes) to the junction. It not only serves as a regulating forebay, giving the water in the comparatively level upper section time to alter its velocity, but also it takes up and relieves all jars that might damage the weaker sections above it.

### Medium-head Lay-outs.

Medium heads will generally be developed either from actual waterfalls or rapids in rivers, or from rivers near the base of mountains where the volume is great and the slope comparatively small. Higher upstream it is generally possible to utilize a high head at less cost, even though a large volume may be available. Where many rapids occur in a short length of bed it may be possible to pipe the water direct from the stream to the power house (Fig. 4 *d*), with a forebay interposed to prevent detritus getting into the pipes. In several American schemes either the whole power house is located at the bottom of a shaft cut down vertically in the rock behind the fall (Fig. 4 *e*), or the turbines are placed in such a shaft and operate generators on the surface. Where there is an actual waterfall, as in many of the largest undertakings, it is seldom necessary to carry the water far to the forebay. Sometimes the pressure pipes can be led directly into the reservoir (Fig. 4 *f*) or into a forebay constructed immediately above the fall; a short canal at most is required, and as it must be of large carrying capacity there is a great saving in such a natural fall.

Where the river has a considerable bed slope, or rapids, it may be necessary to carry the water for

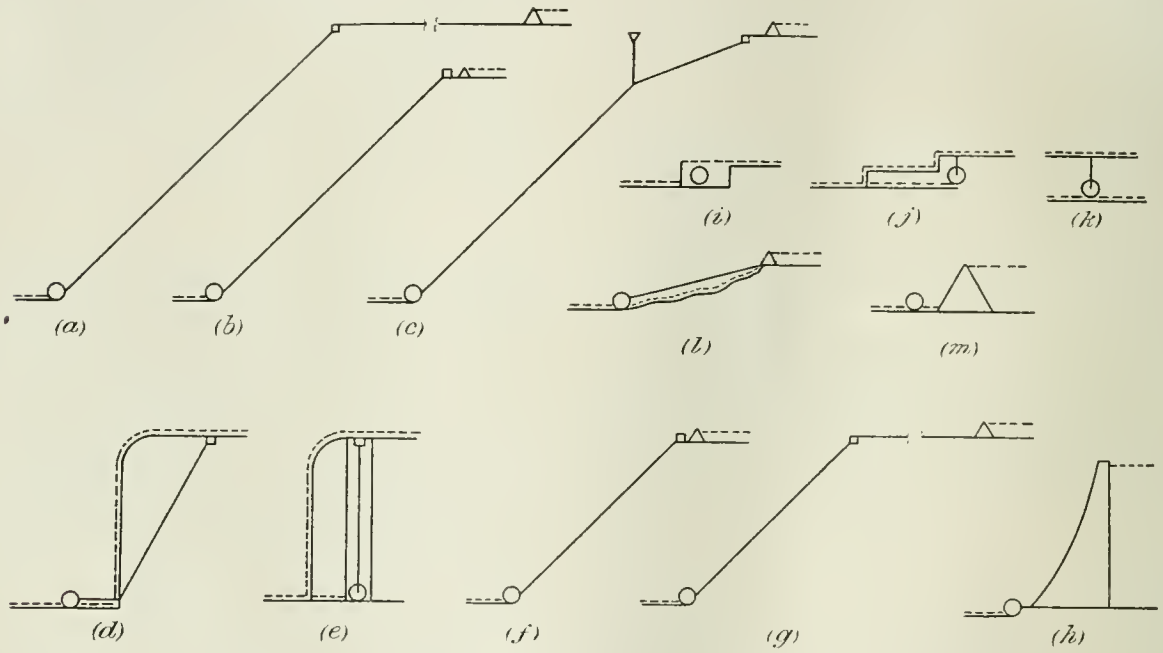



Fig. 4.

miles in a canal (Fig. 4 *g*) in order to accumulate a few hundred feet of fall; and if an earthwork canal is impracticable an artificial flume is required, which adds both to the capital cost and to the liability to breakdown.

As the head decreases, and the volume of water increases, not only the flume but also the pipes increase in size, so that carriage to site often becomes a difficult and expensive problem where the installation is some distance from the railway. Occasionally a medium-head plant may be worked directly from a reservoir behind a high dam (Fig. 4 *h*), but in such cases there will obviously be very large variations of head to contend with, sometimes from full head to none at all; sometimes—in fact generally—such a reservoir will have been built primarily for irrigation purposes, so that beyond a certain minimum the flow is strictly regulated according to season. This detracts from the commercial value of any such scheme.

### Low-head Lay-outs.

Slow-running rivers and canals, with a small bed slope and no falls, cannot ordinarily be used for power purposes, as it is not possible to develop even a low fall without the risk of flooding the surrounding country above the dam; while the rise and fall of both head and tail waters, not necessarily to the same extent, further complicate the problem. Even where a small fall exists or can be made, these factors complicate the design.

In the case of irrigation canals, falls of from 3 to 10 feet are not uncommon, and can be developed by taking a feeder channel as a by-pass to the power house, continuing as the tail race back to the canal below the fall (Fig. 4 *i*). Sometimes a subsidiary canal (generally in the form of a tail race) will enable two neighbouring falls to be combined so far as the turbines are concerned (Fig. 4 *j*). Larger heads, but still of the low type, may occasionally be developed, where irrigation requirements permit, by discharging part of a high-level canal through turbines to a low-level canal (Fig. 4 *k*). All irrigation canal projects suffer from the disadvantage that an occasional closure is necessary—whether for purposes of repair, or because the water is not required, or because it is more urgently required elsewhere.

In the case of rivers, low falls may be developed on the lines already described for medium falls (usually as Fig. 4 *l*)—always bearing in mind the ever-increasing size of channels and pipes as the fall decreases. In addition there are various schemes in which a dam is placed across a river not so much with a view to storing water as for the purpose of obtaining head. Here the water is fed directly from the dam to the turbines (Fig. 4 *m*), which in some cases are placed inside a hollow dam.

Great variations in the level of the head and tail waters are often a feature of low-head river developments, and floods are a serious menace. In some cases, e.g. at the station of the Portland Railway Light and Power Company, Oregon, and at Bhatghar Dam plant in Bombay Presidency, double turbines are installed, one for the maximum head and the second for the reduced fall. Flood gates, as used in irrigation canal headworks, are required to deal with abnormal rises.

### Headworks and Clear Water.

There is always present the liability of bringing down mud and debris from the source of supply to the turbine wheels, though in the case of canals this is not of great importance from the point of view of power development. This liability increases with the head, as torrents take the place of larger rivers, and its effect on the wheel buckets also increases with the head and the spouting velocity of the jet or nozzle. Even the finest grit under a head of 1,500 or 2,000 feet is most destructive, and loss of efficiency soon results from worn nozzles.

Where the headworks have a considerable dam there is no danger from stones or heavy matter except that their deposition will reduce the capacity of the lake; but in hill torrents this in itself is so serious a matter that high dams would seldom be justified. Such a lake could only be cleaned out at great expense, though undersluices may enable the debris to clear itself if there is enough water to spare and if the lake is only of moderate size. If, however, such a dam is necessary it will sometimes pay to put another and smaller one further upstream, simply as a means of arresting the silt for a few years. The capital charges would generally be less than the cost of periodical cleaning out. With lower velocity in the stream such dams are often practicable, though not necessarily at the point where the water is tapped off.

*On high and medium heads.*—Generally speaking, in the case of high- and medium-head plants, a low diversion dam is all that is necessary, sufficient to ensure the possibility of getting the water into the channel or pipe under normal conditions, and also to protect the stream at this point from scouring out the channel and endangering the supply in times of flood. Cases have occurred within the author's experience where a few days' abnormal rainfall have lowered the level of a stream bed 30 or 40 feet. For protecting the banks above and below the headworks boulder crates, made up of large boulders enclosed in a framework of heavy-gauge galvanized wire, have been found invaluable in every sort of river training works. Cases will sometimes be found where a permanent dam is not necessary, the natural lie of the ground alone ensuring the supply. Timber dams are sometimes used in America for levelling the bed.

In the absence of a dam, whether the water is taken direct into pipes or into a channel—but more especially in the former case—arrangements must be made at the headworks for catching all debris. Generally there will be a succession of screens or trash-racks through which the water passes to a small tank, in which any heavy matter coming through will deposit. This will need constant cleaning out, and should (in the absence of other reserve) be in duplicate. Nothing but fairly fine silt should pass beyond it. If there is no open channel this tank should be large enough to remove even such silt as will deposit readily, or there should be an adjoining settling tank for this purpose. Where

there is an open channel there will always be the liability of further debris being collected along it, and a forebay is necessary at the point where the pipes take off; sometimes the lie of the ground makes it convenient to put intermediate silt tanks along the route. All these should be designed for rapid clearance at several exits, controlled by gates of substantial size. By sloping the floor from all points towards the exits the flow may to a great extent be utilized to carry off the deposited mud. The size of these settling tanks should be such as to reduce the normal velocity of flow to a few inches per second. Where there is a reservoir at the pipe head it is still necessary as far as possible to prevent the accumulation of mud in it, as a large volume will become so solid that its clearance is a matter of difficulty, and a silt trap immediately before it will assist in this direction. Where water is considerably in excess of actual requirements it is possible to allow a proportion to run off continuously at the headworks chamber, through partly open sluices, which will pass out all solid matter rolling along the bottom.

*On low heads.*—In the case of low heads the water is generally clear, as low velocity postulates a small bed slope and deposition will occur in the river itself. In any case the quantity to be dealt with is so great that artificial settling cannot be arranged for. Strainers (known in America as trash-racks) are necessary to prevent floating matter entering the pipes, and a forebay may be required to catch anything that may pass through, as well as for regulation. A long canal is seldom necessary, and the forebay will either be at the side of the fall, parallel with the river, or across it on or in a low dam. It depends on the ground whether a diverting dam or anicut is required, or whether a forebay can be opened directly into the bed of the river. In the majority of cases of very low heads the power station is built across the river, and the water flows directly through the strainers into the turbines. In America much trouble is caused by ice on such plants, both from floating blocks and from ground ice (or frazil as it is called there) which forms suddenly from supercooled water where its velocity is checked at the gates. This is dealt with by steam pipes and sometimes even by explosives, and may cause complete stoppage.

### Canals and Open Channels.

In the cases where a very large canal is required in connection with a hydro-electric development, the design is carried out on lines of irrigation canals, to which no further reference is necessary. On medium and high heads the channels, if required, are of a smaller order. They may vary in length from a few hundred yards up to many miles, and may be single, duplicate, or multiple. The De Sabla plant of the Valley Counties Power Company in California collects water from a number of streams by means of ditches aggregating about 100 miles in length, like an inverted irrigation system, smaller channels feeding larger ones up to the forebay.

In the case of long channels a break might only be discovered after many hours; and even if due only to an earth fall, diverting the supply without breaking down the channel, it would take time to get this cleared and the water at the forebay again. In the absence of a substantial reserve at the forebay end this would involve complete breakdown. Water-level indicators, electrically controlled, are therefore often used in these cases. In the 10-mile flume of the Columbia Improvement Company at Tacoma, U.S.A., the indicator shows every inch of rise or fall; and the large capacity of the flume itself forms no inconsiderable reserve. As a motor runs on rails above the flume little time is wasted in reaching the source of trouble.

*On high heads.*—For very high heads a comparatively small discharge is required, and this will sometimes be collected from more than one source and by more than one route. Earthwork channels can seldom be constructed in these cases, and the choice generally lies between galvanized iron (for very small discharges), masonry or concrete, and timber. The first and last have the advantage that they can be carried on a structure without cutting away the ground, at least in the majority of cases. As landslips are always liable to follow the cutting of a roadway on a mountain side this is a great consideration, and an inspection path can be carried alongside or over the channel. If masonry or concrete is used, water running down the hillside behind is stopped at the channel, and either flows into it with mud and stones or sinks in and causes slips. Catch-water drains of substantial size, leading to the nearest culvert, are in such cases essential. Smaller torrents may have to be crossed on bridges, and each of these should be used to afford a discharge outlet for the water in case of accidents and for scouring. Sometimes where water is not over plentiful it will pay to divert these small torrents into the channel through a small settling tank; for, though their discharge may be negligible ordinarily, it may be sufficient in times of heavy rainfall to tide over a breakdown in the channel higher up. Furthermore, when the main stream is in flood, the intake may have to be temporarily closed owing to floating debris, etc.; whereas the flood water of small supplementary streams will probably be clear and much collection of mud in the forebay may thus be avoided. This is not always true, but is borne out generally by the author's experience.

Fairly low velocities, not exceeding $3\frac{1}{2}$ feet per second in unpitched earth channels and 6 feet per second in other kinds, are generally necessary for the preservation of the channel.* The cross-section may be square, semicircular or trapezoidal, the latter being generally the best as giving the smaller hydraulic mean radius. In order to lose as little head as possible (although a few feet on very high heads do not really count much) the slope should be kept small. The inter-relation between slope, velocity, dimensions and the construction and condition of the channel are stated in a number of rival formulæ, none of which are universally applicable; the most useful of these have been discussed by the author elsewhere† and need not be referred to in detail here. In practice the slope is generally decided on first—from 1 in 500 for small channels, to 1 in 1,500 or so for large ones—and the dimensions are calculated to suit. It is very necessary, however, to remember

* For details see Captain Garrett's "Hydraulic Tables and Diagrams" (Longmans).

† "Electrical Engineering Practice," 3rd edition (Spon), pars. 349 to 351.

that any data found by a formula dealing with a straight length of channel will need alteration where there are bends or irregularities. An opening out of the width by an extra 5 or 10 per cent, carried back to the limit of the possible afflux, may be required to prevent overflow, or a corresponding raising of the height or increase in the slope. Uncontrolled overflow would be almost certain to produce landslides and breakdowns. As, apart from faults in design, a small fall of earth may easily cause such an overflow, it is sound practice so to regulate the height of the side wall that overflow will take place most easily at places where it can do no harm, i.e. over solid rock, or into streams passed by the way, or, in the absence of these, down artificial spillways.

In order to prevent the channel being overfilled at the headworks a method often used is to place a diverting place in the fairway at a point near the headworks, such that any flow beyond the capacity of the channel is skimmed off and discharged back to the stream.

Where masonry or concrete channels are used most of the above considerations apply with equal force. Here it is necessary first to cut a roadway for the foundation, so that the liability to landslips and rock falls is greatly increased. Where the ground is at all doubtful cut-and-cover is necessary, and it is better to spend money on revetments to begin with, than to take the chance of bad ground holding up. It is essential to make culverts under, or preferably over, the channel for the very smallest lines of natural drainage, both for safety and to prevent the access of stones to the channel. Often it will be advisable to lay small drains down such places, with cross-collecting drains to prevent a wash-out.

In extreme cases tunnelling may have to be resorted to, for the avoidance of bad ground. It may also pay at times to tunnel through a bluff rather than go round it. Tunnelling on a large scale is also sometimes required either to join up two sources of supply in different watersheds or to lead water collected in one area to a different watershed, where a more convenient or higher fall can be obtained. There are many examples of this class of work in America and elsewhere.

*On medium heads.*—While small works on medium heads may be served by the same methods as apply to high heads, canals in earth are generally necessary. The cost of an artificial channel would generally be prohibitive over a certain size. The largest timber flume the author has seen was at Tacoma, U.S.A., and was 8 feet square and about 10 miles long, with a fall of 7 feet per mile. No other material could be used for a channel of this size, and timber has its drawbacks. Unless the water is running full all the time warping is certain to occur, while boring insects and rot have to be faced. The large flume of the Thelum hydro-electric works has suffered severely in this way.

### Forebay Reservoirs.

Whether the forebay is mainly for regulation, or whether it also holds a considerable reserve supply, it is an important link in the chain. It must be so designed that, while acting as an efficient surge tank, and as a regulator to deal with loads temporarily exceeding the capacity of the channel, it does not allow any foreign matter to get into the supply pipes. Coarse and fine strainers should be provided, and they should be of such breadth that the full flow required by the wheels can pass through them if the water accidentally falls low. This is often overlooked in designing. In some small installations the actual reservoir is at a little distance from the forebay or pentrough, and the two are connected by a closed pipe large enough to deal with the peak load. In such cases the reservoir performs these latter functions, while the forebay proper becomes only a surge tank.

The forebay, or forebay reservoir where these are combined, should if possible be sectionalized or duplicated to admit of cleaning out; and the design should be such as to facilitate this, as suggested above for silt traps. Where the channel discharges into it, which should be at a point as far as possible from the pipe entry, there should first be a small chamber to take eddies and induce still water; this will also catch some of the residual silt, and as its walls will stop a foot or two below normal water-level only the clean overflow will pass into the reservoir proper, and not the bottom layers, except at cleaning-out times. (This of course assumes that the width of the sill is greatly in excess of the width of the channel.) The spill-way and scour valves of the reservoir should be near this point, where most of the mud will collect.

The strainer that finally ensures no foreign matter getting into the pipe requires careful thought. The obvious plan is to put it immediately behind the bell mouths of the pipe, and to close it in at the top. But there is a chance then that some part of it may eventually rust away and get into a nozzle. Repairs would be difficult without emptying the forebay and shutting down the plant, and it has been found in practice that the arrangement is not satisfactory. The alternative design, which should be adopted, is to put the strainers in the main forebay, at the entrance to a separate walled-off chamber feeding the pipe, and this chamber should be covered over. Rolling screens, operated by a winch, are useful because of the facilities they offer for cleaning. A point of importance is that the screens must be capable of passing the full flow when the forebay is nearly empty.

An emergency by-pass from the channel, also provided with a screen, should be made to discharge direct into the bell-mouth chamber. If repairs are required to the reservoir this will prove invaluable, and when the water is running clear it can be used while cleaning out proceeds. These small points of design may spell the difference between success and partial failure, though of course a good deal depends on whether clear or dirty water is generally brought in. For reasons already explained high heads need the most careful treatment. Medium heads may or may not need complicated forebays, and with low heads a plain tank is generally sufficient.

### Pressure Pipes.

There is considerable diversity of opinion as to the best arrangement of pipes for feeding a number of turbines. Apart from the question of cost there can

be no doubt that the ideal arrangement is self-contained units of pipe, turbine, generator and step-up transformer, just as in modern steam practice. Where very large units are involved no other arrangement is likely to be used, and on low heads no other arrangement is generally possible. Intermediate cases must, however, be discussed. Structural design is beyond the scope of this paper, but it may be stated that the diameter of a short pipe on a moderate head may be such as to give a velocity as high as $0{\cdot}1\sqrt{(2gH)}$ or 10 per cent of the spouting velocity. The loss of head with such velocities would soon become too great, and about 3 to 4 feet per second is a good average. On high heads 9 to 12 feet per second in the smallest sections is about the limit used. In a good many instances pipe lines have been brought straight to the power house, and the turbine and generator mounted over the tail race in the same alignment, as in Fig. 5. From every point of view the arrangement in Fig. 6 is preferable. In the first place, a burst pipe will be less likely to flood the power house; in the second place the generators are on a solid foundation instead of being carried over the tail race.

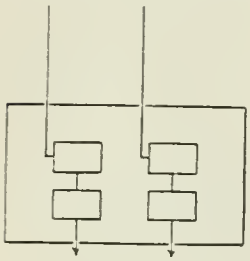


Fig. 5.

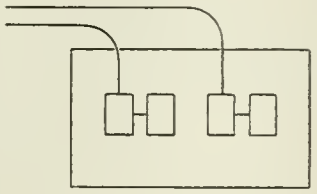


Fig. 6.

*On high heads.*—With very high heads comparatively small pipes of great strength are required; the locality is likely to be far from rail-head, so that carriage to site is an expensive matter. It therefore pays as a rule to keep down the weight of individual loads, and to use a single pipe for each turbine. It is, however, often advisable to interconnect the various pipes at the forebay. Each pipe should be capable of being instantly closed at the forebay in the event of a bad blow-out, either by an automatic valve or by electrical control from the power house. Each pipe must also have an isolating valve at the forebay or a gate in the forebay. Air pipes and filling valve may also be required.

Where conditions are favourable a single pipe is often used to serve two or more units by means of a receiver at the power house, especially in the case of small plants, but this is not ordinarily recommended.

In order to reduce the thickness of the lower sections of pipe it is customary to use two or more diameters, the smaller at the bottom, and this also economizes in freight where they can be nested.

Where individual pipes serve each wheel it is advisable to interconnect them at the power house, so that in the event of a joint blowing on one pipe while another generating unit is out of service they can be cross served. This involves extra expense in isolating valves, but is generally worth it. It is not an identical proposition with the receiver.

Long lines of pipe, such as are required on high heads, require very substantial anchoring not only at the top and bottom but at several intermediate points. These also provide safe positions for expansion joints, which can be dispensed with only where the temperature variations are small or the line has many angles in it—and not always then.

Air valves are not often required, but will be where there is an unavoidable rise in the pipe line. Occasionally air cushions are provided in very long lines, to take up shocks; at the Mill Creek plant in California the pipe is 8,700 feet long for a head of 1,950 feet, and both air valves and cushions are installed. The latter consists of duplicate cylinders for recharging at the necessary high pressure (Fig. 7).

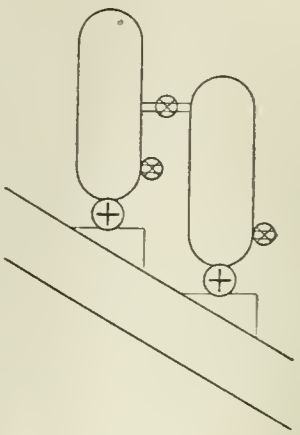


Fig. 7.

Both main valves are first closed and the air and exhaust cocks opened. After closing them No. 2 valve is opened and the air is compressed. This process is repeated until the cylinders are fully charged.

The reduction of effective diameter due either to ordinary furring from lime, etc., or more particularly to fine mud deposited when the water is standing, may seriously increase the loss of head. Although cleaners of the revolving turbine type can remove a good deal of this deposit, the initial diameter should be always greater than is indicated by the velocity decided on.

*On medium heads.*—There are no special points in which the pipe system on medium heads differs from that already dealt with. The pipes are of larger size, and their carriage becomes more serious unless they are built up at site, but on the other hand the locality is generally more accessible. Air valves and cushions are seldom required.

*On low heads.*—With very low heads and submerged turbines the draft tube is the only pipe required, while with somewhat higher heads there will be both pressure pipe and draft tube. With large units of plant the size of the pipes becomes very great and the internal hydraulic pressure becomes a secondary consideration. Cases are on record where an automatic gate, serving a very large pipe, was closed at the forebay and air pressure caused a complete collapse. No interconnection is usually practicable or necessary with low heads.

### Tail Races.

On low-head plants the essentials of the tail race are that it shall be of ample size to give a very low velocity of discharge, and that it shall be free from eddies. A very small loss of head may be a very large percentage of the total—every inch represents 3 per cent on a 3 ft. head—and the draft tube and tail race are just as important as the headworks. Backing up of the tail water from excessive flow may be unavoidable, but bad design may increase it unnecessarily.

With medium and high heads the water has done its work when it leaves the discharge orifice, but it has considerable capacity for mischief left in it. The tail-race pit must ensure that there are no waves tending

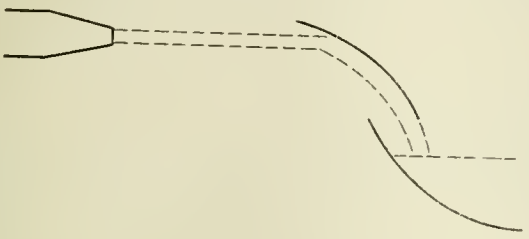


Fig. 8.

to stop the free exit of the water, and it must also cushion the discharge so that the structure is not destroyed. On heads of 2,000 feet or so the destructive effect of the spent jet is surprising, and masonry is quite unable to withstand it. Baulks of timber or cast-iron blocks, which can easily be renewed, are sometimes fixed in the pit. Other arrangements are designed to divert the direction of the discharge to strike the tail-race water horizontally, by means of one or more curved vanes, when a long tail-race pit will act as an effective cushion (Fig. 8). At the Kern Canyon power station, near Bakersfield, California, this arrangement was used even where the jet was diverted below the buckets, under the full pressure of 900 ft. head. In most cases, however, the lowered jet has a free path over the tail race and spouts directly into (or across) the river below.

### Conclusion.

The general description of the lay-out of hydro-electric schemes in all their many forms has made this paper unduly long without entering into any details of actual design. A word must, however, be said in conclusion with regard to cost. From the generator onwards there is no great difference in capital cost between steam and hydro-electric stations, and the cost of the power-house buildings will be comparable. The boilers, steam pipes, engines or steam turbines, condensing plant and accessories are replaced by the comparatively simple turbine wheels and their supply pipes in the most favourable cases; but in less simple plants there is also the whole cost of the hydraulic development, channels, forebays, reservoirs and dams, to set off against the steam plant.

The working expenses—staff, management, lubricants and stores, maintenance and repairs—do not differ in principle in the two instances; practically the annual cost of fuel in the one case must be set off against the extra annual capital charges in the other. The total cost of fuel is proportional roughly to the number of units generated, and expressed in pence per unit it remains sensibly constant in any undertaking. On the other hand, the total annual costs of a hydro-electric station are practically fixed, so that the cost per unit varies inversely as the number of units generated. In both cases the capital cost, and consequent annual capital charges, vary largely with the load factor. An important difference between steam and hydraulic working lies in the fact that every unit generated by the former method costs a definite sum in cash for fuel, so that actual loss would result in selling at that figure; whereas with water power there is no such cash expenditure and any sales which will fill up hollows in the load curve without affecting the peak must be profitable at whatever rate they bring in. The common idea that water power costs nothing is true only in this limited instance. In any such comparison capital cost, cost of fuel, and load factor are the three essentials which determine whether a project can best be served by fuel or by water power.

# NOTES ON SURFACE CONDENSING PLANTS, WITH SPECIAL REFERENCE TO THE REQUIREMENTS OF LARGE POWER STATIONS.

By R. J. KAULA, Member.

(*Paper received* 20 *January*, 1919; *read before* THE INSTITUTION 10 *April, and before the* SOUTH MIDLAND CENTRE 26 *March*, 1919.)

During the last few years a number of papers have been read before this and other Institutions on the subject of condensing plants. The author feels, however, that in view of the impending construction of a number of so-called super-power stations, a general survey of the subject may not be out of place. In the present paper he proposes chiefly to discuss some problems relating to the design of surface condensers and to the general arrangement and lay-out of condensing plants.

Whilst these notes are confined to plants of the surface type, it is not intended to depreciate the value of jet and ejector condensers. There have been marked improvements latterly in the design of low-level jet plants, which have enabled them to supersede the barometric type with its cumbersome exhaust pipe lines. Apart from the question of feed-water supply, low-level jet plants are still at a disadvantage in several respects compared with surface plants. In the first place, the quantity of air carried into the condenser with the circulating water calls for a very considerable addition to the air-pump capacity and power consumption. Secondly, it is rarely possible to utilize the whole of the vacuum head for raising the circulating water, and consequently the total power consumption on the circulating-water side is generally higher than on a corresponding surface plant. Lastly, the shape and size are such as to call for very extensive headroom in the condenser pit. Even so, there are probably many instances, especially in medium-size plants, where surface condensers have been and are being installed and where the use of low-level jet plants would have resulted in a material saving in first cost, without this being outweighed in other directions.

TABLE 1.

| Steam Inlet | | Turbine Efficiency, per cent | Heat Units Rejected, therms | Latent Heat, therms |
|---|---|---|---|---|
| Pressure, lb. per sq. in. abs. | Superheat, deg. F. | | | |
| 300 | 250 | 80 | 1,006 | 1,043 |
| 200 | 200 | 75 | 1,028 | 1,043 |
| 150 | 100 | 70 | 1,017 | 1,043 |
| 150 | 100 | 65 | 1,035 | 1,043 |
| 14·7 | 0 | 60 | 1,051 | 1,043 |

In most condenser calculations it is assumed that the heat quantity to be absorbed by the cooling medium is the latent heat of the steam corresponding to the pressure of condensation.

Table 1 gives the heat units rejected to the condenser per lb. of steam for a few typical initial steam conditions and turbine efficiencies, on the basis of an exhaust pressure of 1 lb. absolute. It will be seen that under the more usual conditions the latent heat slightly exceeds the actual value to be dealt with, so that there is a corresponding margin in hand. Since, however, most constants derived from test results make no allowance for this difference, it is the more important that a correction should be introduced where the heat units exceed the latent-heat figure.

In estimating the quantity of cooling water a further slight inaccuracy is accepted, in that the specific heat of the water is taken as unity, regardless of its consistency and temperature.

On these assumptions, the quantity of cooling water required per lb. of steam to be condensed is, in lb.,

$$W=\frac{H}{T_2-T_1} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where H = latent heat in therms,

$T_1$ = cooling water inlet temperature in ° F.,

and $T_2$ = ,, ,, outlet temperature in ° F.

The difference $\theta_2$ between $T_2$ and the temperature of the steam at the pressure of condensation $T_0$ is to a large extent a measure of the efficiency of a condenser. Whilst test results frequently show $\theta_2$ as low as 5 degrees F., or even 4 degrees F., it is well to estimate on 8 or 9 degrees F., so as to ensure an ample margin of cooling water under all conditions of working.

The amount of surface area to be allowed for a given duty of condensation is an ever-recurring source of discussion. On the one hand, the designer and manufacturer aim at attaining the required result with the smallest expenditure of cooling surface. On the other hand, the user wishes to ensure that his condenser contains a sufficient margin of cooling surface to enable him to maintain his intended vacuum in daily commercial use without being compelled to have recourse to incessant cleaning of tubes.

It is as well to examine the conditions determining

the cooling surface of a condenser. Formula (2) below was, the author believes, first developed by Hausbrand.

$$S = \frac{Q\,H}{T_m\,K} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where S = cooling surface in sq. ft.,
Q = quantity of steam to be condensed per hour in lb.,
H = latent heat at pressure of condensation in therms,
$T_m$ = mean temperature rise in degrees F.,
$$= \frac{T_2 - T_1}{\log_e [(T_0 - T_1)/\theta_2]},$$
and K = heat-transmission coefficient in therms per sq. ft. per hour per degree F.

Since $\theta_2$ is usually predetermined and the remaining factors in the formula are fixed, as conditions to be attained, S may be said to vary inversely as K. Up to a comparatively late date K was taken at a figure varying from 300 to 500. But it has been proved that K for a given condenser design varies distinctly with the cooling water velocity V.

For values of V ranging from 3 ft. to 6 ft. per second, K may be taken as a function of the square root of V. For lower velocities the rate of variation is, no doubt, greater owing to the almost entire absence of turbulence, and for higher velocities the curve flattens out somewhat. If therefore the surface is increased to obtain a margin, this will only be fully effective provided that the water velocity is maintained.

K, and with it the effective use of the surface provided, are naturally also dependent on efficient air extraction and on features of general design, such as the ratio of length to diameter and the careful design of the steam-inlet passage to ensure that all parts of the uppermost tube area come within the steam path. Whilst in no way wishing to disparage the value of an ample allowance in cooling surface to guard against a rapid falling off in vacuum with comparatively slight fouling of the tubes, it cannot be sufficiently emphasized that the bare measure of the tube area presents no gauge of the margin available.

The degree of dryness of a tube is known to have a material effect on its heat-transmission coefficient, and it follows that in this respect the tubes nearest to the steam-inlet opening are more effective than those placed lower down, which may be assumed to be coated with a water film. In view of this known fact it was felt that a marked disproportion might exist in the work of condensation done by the upper as compared with the lower tubes. With a view to obtaining some guidance on this question, arrangements were made by Messrs. Willans & Robinson, Ltd., with Mr. Bishop, of Dundee Corporation Electricity Department, in Major Richardson's absence, to carry out a series of tests on a three-flow 5,000-kw. condenser. The results are set out in the Appendix, and the mean of the readings shows a comparatively slight difference in performance between the three passes. A single series of readings such as that given, and carried out under everyday working conditions, cannot of course be taken as a basis of any very definite conclusions, but they seem to show that the difference in the thickness of the water film is not very marked. The more recent development of condenser design tends to reduce the drop in pressure across the tube nests to a minimum, notably by means of ample steam lanes, and this helps to provide a maximum number of tubes within what may be termed the dry zone.

The provision of steam baffles in the tube space has now been entirely abandoned as being harmful rather than otherwise. On the other hand, guide vanes in the steam inlet opening are frequently introduced to assist the initial distribution of the steam.

The ratio of length to diameter needs to be kept reasonably low, to avoid the formation of dead pockets at either end of the condenser, and a practical working limit for L/D may be taken at 2, whilst a value of 1·5 should be aimed at.

The counter-current principle is, and has been for many years, almost universally adopted in surface condenser design for land work, that is to say, the water enters the condenser at the bottom and is discharged at the top, or, in other words, the direction of the flow of the water is opposite to that of the steam. With wet-type air pumps using the condensate as sealing water, this system is practically a necessity, as the condensate requires to be cooled over the lower tubes before entering the air pump. Since the majority of modern plants use dry pumps,* this point does not require the same consideration, and the higher condensate temperature obtainable with a parallel-flow condenser would be a decided advantage. On the other hand, the increased temperature of the air and vapour mixture leaving the condenser has to be counted a drawback, for reasons which are explained below.

If we consider the effect of reversing the usual arrangement of the water path on the circulating-water piping immediately before and beyond the condenser, it will be found that in some instances this would facilitate design, and in others the reverse would hold. It would be, no doubt, of some assistance to the designer of the lay-out not to be tied in this respect as at present.

The main object, however, in drawing attention to this question is the advantage to be derived on a syphonic circulating-water system by adopting the parallel-flow principle. In a complex pipe system, involving many bends and changes of water velocity inevitable in the circulating-water system of a condensing plant, it is not possible to rely upon maintaining the complete syphonic vacuum corresponding to the static head available for the purpose. It is reasonable to assume that the loss in vacuum is proportionately greater on a high vacuum than on a low vacuum. If we assume that the "syphonic efficiency" varies in a straight line from 100 per cent at zero head to 70 per cent at 34 ft. head, then the curves drawn in Fig. 1 show the total head on the circulating pump, apart from pipe friction, assuming 8 ft. condenser friction and 8 ft. between centres of water inlet and outlet branches for parallel and counter-current condensers. The difference be-

* The terms "wet" and "dry" air pumps are here used in accordance with common practice, to differentiate between pumps extracting the condensate as well as the air and those dealing with the air only. Where the latter form of pump consists of nothing more than a water jet, the use of the adjective "dry" is of course paradoxical.

tween the two curves indicates the saving in head obtainable. It will be seen that the saving only reaches a substantial amount where the distance from water-level to the highest point of the system is considerable. On the other hand, the reduction in syphonic vacuum

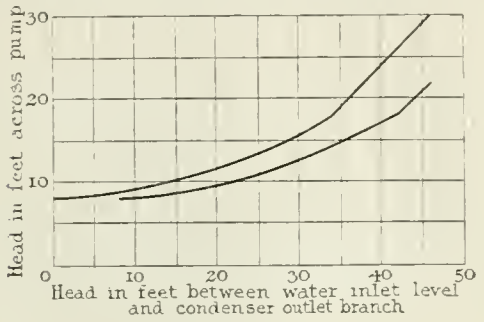



FIG. 1.

to be maintained on a low-head system is in itself a considerable advantage. Fig. 2 shows the corresponding pressures and vacua to be maintained for a few typical heads.

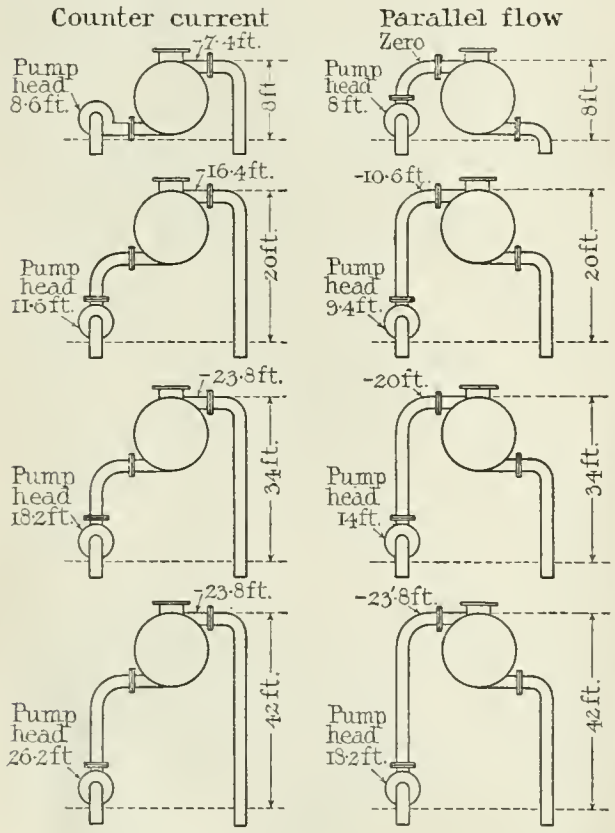



FIG. 2.

It is not suggested that the parallel-flow principle possesses such advantages as to warrant its general adoption, but there would appear to be good grounds for its use on syphonic circulating-water systems.

As far as the user is concerned, there is little to choose between cast-iron and wrought-steel shells. Cast-iron shells are considered liable to crack when the turbine is changing from atmospheric exhaust to vacuum, and vice versa. On the other hand, wrought steel is liable to be subject to corrosion.

As a matter of experience, the author has not heard of a single instance where a cast-iron shell has actually cracked except in the course of manufacture, but it must be admitted that it is a possibility which the station staff always view with some anxiety. Unfortunately, the railway gauge necessitates the introduction of both vertical and horizontal joints in large cast-iron shells, thereby adding materially to the machining costs and to the cost and time of erection on site.

At the present time it is useless to attempt to compare the cost of shells made of the two materials as a guide to normal conditions, but it seems unlikely that cast iron will prove economical in peace time for sizes of, say, 20,000 sq. ft. and upwards.

In land practice the water velocity in the tubes varies usually between limits of 4 ft. and 7 ft. per second, depend-

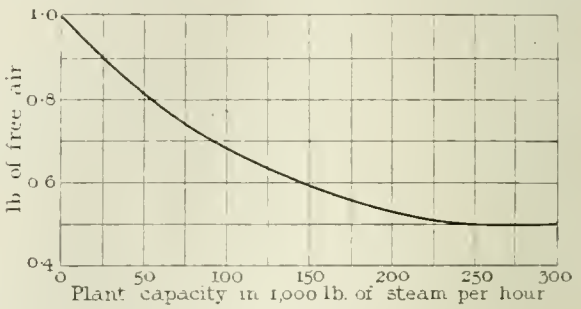



FIG. 3.—Curve showing lb. of free air at atmospheric pressure and at 60° F. per 1,000 lb. of steam.

ing on the permissible friction loss and the attaining of a suitable shape for the condenser. The friction loss varies with the square of the water velocity and may be divided into the following items:—

Loss in the tubes themselves .. .. .. I
,, at tube inlet and outlet .. .. .. .. II
,, in the water boxes and inlet and outlet branches III

Whereas I is simply determined by the diameter and length of tube selected, II and III will vary according to the care exercised by designers and draughtsmen. By providing suitable bellmouths on the ferrules a saving can be obtained on II without materially adding to the cost of production. The designer is often tempted, as a convenience in the lay-out, to adopt sharp right-angle bends at the inlet and outlet branches, but these should be avoided wherever possible, especially at the inlet, as the waste in friction head may reach quite a substantial figure.

It is not proposed to describe at length the various forms of air pump now on the market, but a brief consideration of the problem of air extraction from a condenser may not be out of place. The quantity of air to be dealt with depends on the number and condition of joints under vacuum, on the air-tightness of the turbine glands, and on the quantity of air carried

over with the steam. Since the peripheries of the joints and glands vary approximately as the square root of the output of the plant, the quantity of air to be allowed per lb. of steam condensed should be materially less on a large unit than on a small one. The variations in air-pump capacity called for in purchasers' specifications indicate a considerable divergence of opinion as to what constitutes a reasonable allowance in this respect. It would seem very desirable that some form of standard should be established, to which all condenser makers could work, and the curve shown in Fig. 3 is put forward as a suggested basis for high-pressure turbine plants where the condenser is mounted immediately below the turbine. It is naturally important that the air-pump capacity should be ample; at the same time an excessive margin means a continuous waste of auxiliary power.

The necessary volumetric capacity of the air pump to deal with a given quantity of free air is

$$V_o = \frac{V_1 P_1}{P_o},$$

where $V_1$ = volume of air at atmospheric pressure,
$P_1$ = atmospheric pressure,
$P_o$ = partial air pressure at the air-pump suction.

Since the volume of the air varies directly as its absolute temperature, and the difference between air inlet and outlet temperature is not likely to equal 1 per cent of the absolute temperature, it is reasonable to neglect the question of air temperature as affecting its volume at a given pressure.

According to Dalton's Law, the total pressure $P_v$, i.e. the pressure corresponding to the vacuum to be maintained, is the sum of the vapour pressure $P_s$ and the partial air pressure. Hence $P_o = P_v - P_s$. Assuming the air to leave the condenser in a saturated condition, then $P_s$ is the pressure of dry saturated steam at the temperature of the mixture, and it follows that $P_o$, and with it $V_o$, depend materially on the temperature of the mixture in the condition in which it enters the pump.

In a wet-air pump the mixture is in immediate contact with the sealing water, and its temperature is reduced to approximately that of the latter. In rotary air pumps it is generally assumed that the mixture in coming into contact with the water jet assumes the temperature of the jet, that is to say that the air pump fulfils the function of an air cooler before and in addition to acting as a pump. It seems doubtful whether the cooling is carried out without impairing the primary function of the pump, and a number of designers prefer to cool the mixture by passing it over a batch of tubes taking their supply of water from the circulating-water inlet. In a parallel-flow condenser the temperature of the mixture would naturally be higher than in a counter-current condenser, and this precaution would therefore be all the more necessary.

Modern types of air pumps can be divided under three headings:—

(1) Reciprocating pumps,
(2) Rotary air pumps,
(3) Steam ejector pumps.

The Edwards pump is the only example of the first group which can still claim to hold its own even in the largest installations, but where vacua of over 27½ inches to 28 inches are concerned it may be ruled out, except in conjunction with a vacuum augmentor. Its comparatively low power consumption, reliability, and low maintenance cost are its chief advantages. Where a vacuum augmentor is in use the steam consumed by the jet requires to be added to the pump power-consumption, and in practice this amounts to anything from 0·5 to 1 per cent of the main turbine consumption, whereas the pump itself should not consume more than about 0·2 per cent of the turbine power. The disadvantages of the Edwards pump are its bulk and its low running speed, and where the pump uses the condensate as sealing water the temperature of the latter needs to be kept low, and the condensate becomes strongly aerated—a frequent source of boiler troubles.

All rotary types of air pump consist of one or more water jets, which entrain and compress the air. In the case of the kinetic system, the water jet works in series with a steam jet. The characteristic of the earlier designs was such as to show very little difference in capacity between high and low vacua, with the result that the time taken to evacuate was excessive, and anything in the nature of a heavy air leak caused a sharp fall in vacuum. These disabilities have been overcome in later designs, but the efficiency of such pumps is still very low, and it is reasonable to expect a marked improvement in this respect as designs develop.

The steam ejector type of air pump represents a development of the Parsons vacuum augmentor. In their simplicity they equal the water-jet type, with the advantage of using pipes of small dimensions instead of comparatively heavy water pipes. In the matter of power consumption, it is claimed that although the quantity of steam consumed is appreciable, practically the whole of the heat value is returned to the feed water, so that the actual loss of heat is well below that of any other system. This claim requires some qualification, as in the first place a similar result can be obtained by driving a rotary pump with a back-pressure turbine exhausting into a feed heater, and secondly, with the condensate temperature within a few degrees of vacuum temperature, and efficient economizers in use, the number of heat units which the feed water can absorb in this manner economically is limited. However, there can be little doubt that the claims of the steam ejector are strong enough to ensure its success and widespread application.

The failure of an air pump does not in itself involve an immediate change to atmosphere, as the consequent accumulation of air in the condenser is very gradual where the system is reasonably air-tight. Provision should therefore be made, where necessary, by means of suitable non-return valves, to ensure that such a failure is not accompanied by an inrush of air through the air pump.

The introduction of rotary air pumps brought in its train the general use of separate condensate pumps. The conditions to be met are such as to impose the utmost difficulty on the design of a pump of the centrifugal type. It is not therefore surprising that a good

number of failures required to be overcome, and much practical experience had to be gained before satisfactory designs were evolved. It is now appreciated that low water velocities on the suction side are essential, as well as in the impeller, to guard against cavitation troubles. To ensure these conditions, and stability over the large range of fluctuating loads which such pumps are called upon to handle, it is well to work on the lower or flat part of the pump characteristic, that is to say, well below the point of maximum efficiency. Since the total power involved is small, the question of efficiency is not of material consequence.

An ample static head on the suction side is required to overcome pipe friction and to ensure that the water enters the pump with a sufficient initial velocity. The connecting pipes between the condenser and the pump should be as short as the lay-out will permit, with a minimum number of joints. Unfortunately, the same reasons for inserting non-return valves on the suction side apply to condensate as to air pumps.

The circulating pump forms a vital link in the chain of apparatus that constitutes a condensing plant, as regards continuity of running, since its failure for however short a period means an immediate and complete failure of the vacuum.

Reliability is therefore naturally a first consideration. At the same time the power consumption is comparatively high, so that a high efficiency needs also to be looked for.

The material of the shaft and impeller require of course to be selected to suit the nature of the water.

Since all but the smallest circulating pumps are of the double impeller type, balancers are not usually needed. It is, however, advisable to avoid pipe bends in the horizontal plane in close proximity to the suction inlet, as they are apt to produce an uneven distribution of the water over the two halves of the impeller and to throw the pump out of balance. Even when the water levels are constant, provision should be made for reasonable variations in head, as it is not possible to predetermine the friction heads within a few per cent, and they are in any case dependent on the condition of the pipes and condenser tubes.

The characteristics of the pump should be adapted to that of its prime mover, and when this latter permits of speed regulation the pump should be able to take full advantage of this feature without loss of efficiency. It is then possible to regulate the water supply, according to the head, by varying the pump speed, and this method is much to be preferred to throttling.

In large power stations it is customary to provide separate turbo-generating units for supplying the power to all auxiliary machinery, and for lighting purposes, so as to ensure complete independence of the main plant.

Now that there is no difficulty in obtaining gearing for driving the generators, there is nothing to choose in the matter of first cost or economy between three-phase and direct-current supply for this purpose.

The possibility of obtaining speed variation is a marked advantage in favour of the latter system, and this applies particularly to the circulating pumps.

In smaller stations, where the total power consumption of the auxiliary machinery is hardly sufficient to warrant the provision of such auxiliary units, the necessity of starting up on atmosphere after a complete shut down, where electric motors are used for driving the condenser pumps, has led to the extensive adoption of steam-turbine driven pumps.

Since the power consumption of the condensate pumps is too small for a separate turbine drive, a steam drive can only be arranged by coupling this pump to the air pump or by coupling the three pumps to a single turbine. Such an arrangement, however, has considerable drawbacks. In the first place, the normal speeds of the pumps have no relation to one another, and if the circulating-pump speed is forced up to suit that of the condensate pump, this involves excessively long shafts and small clearances.

Then, again, the pipe connections are very difficult to arrange, and the placing in line of so many shafts gives every opportunity for the appearance of resonant vibrations.

Under the circumstances, it seems preferable to drive the condensate pump electrically, particularly since the plant can be started on vacuum with this pump standing. The condensate will accumulate in the bottom of the condenser until it is forced over into the air pump.

If the steam consumed by the combined air and circulating pumps is excessive for feed-heating purposes, as in fact is usually the case, it becomes necessary to provide separate drives for the two pumps, or to build the auxiliary turbine of the pass-out type. Such steam as cannot be utilized in the feed heater can either exhaust into the condenser or into the low-pressure stages of the main turbine.

The former system is rather extravagant in steam consumption, although where a gear drive is adopted it is quite possible to obtain a very fair efficiency in turbines of 200 to 300 h.p. and upwards. If the auxiliary turbine exhausts into the low-pressure stage of the main turbine the economy will be found to be about equal to that obtained with electric driving, but the complications which this introduces into the construction of the main turbine are undesirable, and additional steam space is required in the low-pressure blading just where it is hardest to obtain.

Apart from the absence of speed regulation, already referred to, an induction motor drive off the main supply is not to be recommended, especially on fluctuating loads, in that a rush of load means a fall in frequency, and consequently of the pump speed, at a time when the pumps should be working at their maximum capacity.

Since, apart from a limited amount of saving that can be obtained at lighter loads by speed regulation or throttling, the power consumed by the condenser auxiliaries represents a constant loss, their most economical arrangement deserves the closest attention.

So many factors enter into the question which vary with the conditions prevailing in each individual station, that it has only been possible to consider the subject on very general lines.

In a modern power station, where the water quantity to be dealt with amounts to hundreds of thousands

of gallons per minute, the means of handling the water is a primary consideration in the design and lay-out of the engine house. If we consider first the simplest case of a non-tidal riverside station, where the river level coincides with the condenser basement level, in such a case the most satisfactory plan is to allow the water to flow by gravity in an open concrete duct into the engine room, with branches leading from the main duct to each pump, the latter being placed close to the condensers. The discharge pipes from the condensers should be led into a corresponding outlet duct, in which the water is maintained at a sufficient level to enable it to return to the river by gravity. A similar arrangement can be adopted in a cooling

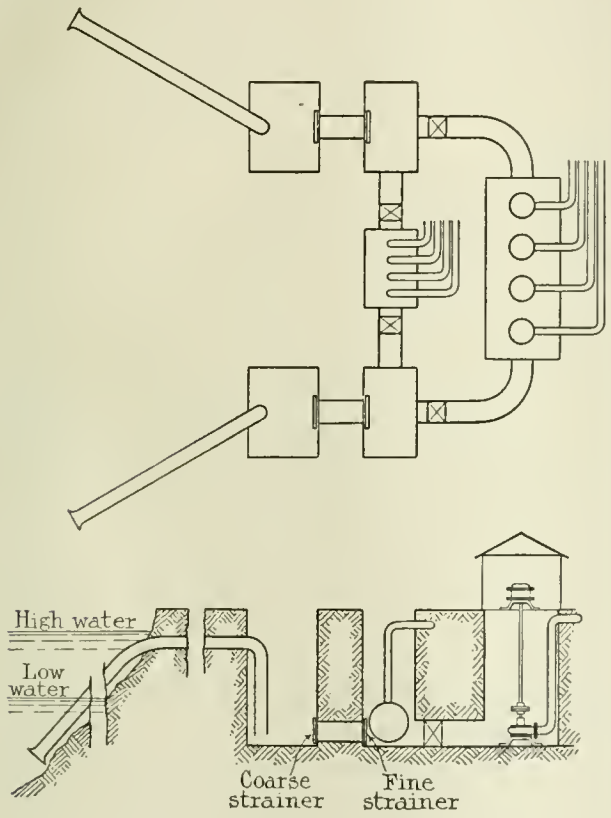



Fig. 4.

tower station, if separate pumping plant is provided alongside the towers to deliver the water to the top of the towers. This arrangement of separate pumps has much to be said in its favour in any case, as it makes it possible to adjust the number of towers in use according to the atmospheric conditions and independently of the number of condensers on load. Where the water-level conditions prohibit the use of open ducts, it is preferable in large stations to run separate pipe lines for each unit.

Perhaps the most difficult condition to be dealt with is that of a tidal river containing large quantities of solid matter which require to be strained before the water enters the condenser. Fig. 4 shows a diagrammatic arrangement of strainers and pumps to deal with such conditions. The water is syphoned from the river into a strainer chamber, and passes from there through two sets of grid strainers into a clean water chamber, and then to the pump house. The strainer chamber and clean water chamber are duplicated, so that the flow of water may be reversed for the purpose of clearing the strainers, and at the same time to prevent silting of the main pipe inlets. The discharge pipes from the condensers are led into a discharge chamber, their outlets being below water level. Valves are shown between the clean water chambers and the pump house and discharge chamber to give the required reversal of flow. Such an arrangement is naturally high in first cost, but this would be fully warranted in the case of a large power station under the conditions named. In smaller plants, and where no great difference in water levels has to be dealt with, strainers of the endless-chain type, with water-jet cleaning gear, as first introduced by Messrs. Dickinson & Porter at Leeds, are generally effective. So-called revolving strainers, such as the Bailey and Jackson type, are too cumbersome for large plants, and the inevitable leakage loss is a considerable drawback to their use.

This question of straining the circulating water is nearly always one requiring much consideration in the case of riverside stations, and should be taken account of in making comparisons with cooling-tower propositions.

Where towers are in use, it will usually be found to pay to soften the make-up water if the latter is at all hard, but such a process would be prohibitive in cost if applied to the whole bulk of the cooling water. This apparent advantage of cooling towers is partly offset by the fact that softening is more important where they are used owing to the higher cooling water temperature in the condenser tubes. When the formation of scale cannot be avoided, the brushing out of tubes is rarely completely effective, and the only remedy is boiling out with hydrochloric acid.

It follows from formulæ (1) and (2) that as the difference between vacuum temperature $T_1$ decreases, so the rate of increase of cooling-water quantity and surface to be allowed rises. Since it is customary in modern practice to work on a rapidly rising part of the resultant curves, a very substantial reduction in water quantity and surface will show a comparatively moderate reduction in vacuum. Thus a condenser designed for a vacuum of $28\frac{1}{2}$ inches (Bar. 30 inches) with cooling water at 70° F. will still be capable of maintaining a vacuum of 27 inches (Bar. 30 inches) if the cooling water quantity and surface are halved, and when dealing with the same quantity of steam. If therefore a condensing plant is arranged to consist of two condenser bodies with separate water connections and valves, it is possible to open up the water side of one condenser at a time for cleaning purposes, and to continue running at approximately full load without a heavy loss of vacuum. It is, of course, not possible to remove tubes under such conditions, as the inactive condenser remains under vacuum. Naturally, such an arrangement means a substantial increase in

first cost, greatly complicates the general lay-out of the whole plant, and can only be justified where the water conditions are exceedingly poor.

Several makers have introduced condenser designs in which the same result is obtained in a single condenser by splitting the water ways and doors. Such designs overcome the primary difficulties of the lay-out, but the complications of pipe work and valves are not in any way reduced.

A special Committee is now investigating the problem of tube erosion, and their report when available will no doubt mark a substantial advance in the process of solving this question. In the meantime, it may suffice to say that no individual metal or alloy has proved immune in all cases. Protection devices, such as the Harris Anderson and Cumberland, have been very helpful in many instances that have come under the author's notice.

In conclusion, the author regrets that it has not been possible to embody further test results in the present notes, but it is at all times difficult to obtain reliable condenser figures under working conditions, and under war conditions it has been found impracticable to do so.

## APPENDIX.

TEST RESULTS CARRIED OUT ON A 5,000-KW. WILLANS & ROBINSON CONDENSER AT DUNDEE CORPORATION ELECTRICITY WORKS AT CAROLINA PORT.

No. of flows=3.
Cooling surface=9,250 sq. ft.
Tubes=$\frac{3}{1}$ in. diameter, 18 gauge.
Air pump=three-flow Edwards type with vacuum augmenter.

Each set of figures represents the mean of a series of readings taken over varying periods showing only slight variations.

The vacuum readings were taken on an absolute mercury gauge placed at the turbine exhaust.

The temperature readings were taken with ordinary mercury thermometers, which were checked and found to read correctly.

The steam quantity dealt with in the condenser was measured on the station Lea recorder.

Tests I and II were carried out with the condenser in a partially dirty condition. The condenser was well cleaned between Tests II and III.

The water temperature readings A, B, C, D, represent readings taken at inlet, first pass, second pass, and outlet respectively.

| Test | Date | Steam | | Vacuum at 30 in. Bar | Water Temperature | | | | Steam per Hour | $K_1$ | $K_2$ | $K_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Inlet Temperature | Outlet Temperature | | A | B | C | D | | | | |
| | | °F. | °F. | in. | °F. | °F. | °F. | °F. | lb. | | | |
| I | 15/9/16 | 102·4 | 96·5 | 28·0 | 56·6 | 71·4 | 80·6 | 88·6 | 80,500 | 437 | 333 | 374 |
| II | 15/9/16 | 98·8 | 92·6 | 28·2 | 56·0 | 69·5 | 78·2 | 85·5 | 73,500 | 370 | 380 | 430 |
| III | 18/9/16 | 93·9 | 80·3 | 28·4 | 56·0 | 69·0 | 78·5 | 85·5 | 81,600 | 720 | 531 | 501 |
| IV | 18/9/16 | 88·9 | 75·4 | 28·6 | 55·7 | 66·1 | 75·2 | 81·0 | 69,500 | 602 | 620 | 420 |
| V | 18/9/16 | 73·6 | 66·2 | 29·1 | 55·0 | 61·0 | 65·2 | 69·0 | 35,500 | 590 | 465 | 486 |
| VI | 18/9/16 | 91·0 | 77·5 | 28·5 | 55·0 | 67·0 | 75·0 | 82·5 | 80,000 | 680 | 470 | 548 |
| VII | 19/9/16 | 94·4 | 82·0 | 28·4 | 55·0 | 68·0 | 79·0 | 82·7 | 82,700 | 334 | 680 | 620 |
| | | | | Mean .. | .. | .. | .. | .. | .. | .. | 535 | 496 | 466 |

The figures given in columns headed $K_1$, $K_2$, and $K_3$, represent the calculated heat-transmission coefficient for the top, intermediate, and bottom passes respectively. These have been arrived at in the following manner:—The steam quantity dealt with in each pass was apportioned from the total from the water temperature readings. The vacuum for the top pass was taken in each case at 0·1 inch above that measured at the turbine exhaust. A further drop in pressure of 0·1 inch was allowed across each pass, except in the case of Test V, where the drop was taken at 0·05 inch per pass. With these assumptions, K was derived in each case from Formula II.

Discussion before The Institution, 10 April, 1919.

**Mr. F. Bailey**: It is unfortunate that the time has not yet arrived when it is possible to standardize condensing plants, and at the present time any system on which we can compare notes and experiences with regard to the various methods of obtaining a vacuum is of great utility. Many of us are attempting to use ejectors, with the result that one finds numerous variations in the power required to obtain a certain vacuum as compared with other methods. In one case to obtain the desired vacuum we required 45 kw. for plant of about 3,000 kw. capacity, and in another case something like 74 kw. for 4,000 kw. of plant by a totally different method, but with the advantage that for the 74 kw. we could always rely on obtaining a vacuum within 1 inch of the maximum. With turbines every fraction of an inch extra vacuum we can get is of material advantage and justifies the expense of the plant and any running costs. After all, we naturally want to obtain plant, at the lowest cost, which will work with absolute reliability and at the same time give the required result with the least amount of circulating water and with the least trouble. Our desire is to get away from the use of the reciprocating air pump, much as we appreciated the Edwards pump when it first came out, but the difficulty always seems to be to run such a plant with the bearings true and efficiently lubricated. In connection with the condenser, the author rightly remarks that the matter of prime importance is clean circulating water, and he mentions the great difficulties there are in some cases of obtaining it from a tidal river containing large quantities of solid matter which requires to be strained before the water enters the condenser. In attempting to obtain clean water it has been my lot to try to extract from the water a certain amount of vegetable fibre and refuse, and I can fully endorse all that the author has said with regard to that trouble. The particular arrangement described in Fig. 4 happens to be precisely the arrangement originally provided by the City of London Electric Lighting Company in their efforts to obtain clean water, and the arrangement worked very well when the water was clean, and they thought that perhaps once per day would be sufficient to reverse the flow against the straining pit, but as a matter of fact it required to be done every hour. The result was that the whole plant ceased to work condensing, and we were very soon told we must shut down or stop the nuisance. It was necessary at short notice to install some sort of appliances and our arrangement turned out successful and is working at the present day, although it goes back 24 years. The author also mentions that the so-called "revolving strainers" such as the Bailey & Jackson type are too cumbersome for large plants, and that the inevitable leakage loss is a considerable drawback to their use. If that were true of course it would naturally be a great disadvantage, but fortunately in this, as in everything else, we endeavour to improve, and the original apparatus although still at work has undergone certain improvements. It is one of the things we have to rely upon as a piece of plant that is absolutely essential. I need only mention that, in the type we are now using, a machine which was originally 10 ft. in diameter can now do the work if 6 ft. diameter, and the leakage is now reduced to 2 per cent. As regards ejector extractors, there seems to be a great difference in the steam consumption required by various plants. The author mentions that there is some difficulty in obtaining the whole benefit of the steam in such appliances, especially as it is guaranteed that 83 per cent will be recovered from an ejector of this type; but considering the small percentage of steam used in the plant I do not think that there should be any insuperable difficulty in getting satisfactory service from that amount, and hence there should be no loss in applying these new appliances. Several very useful hints are given by the author, especially in the aeration of the condensate. That is a point to which attention has not been drawn in the past, with the result that a certain amount of corrosion can be traced to the aeration of the condensate by using appliances well adapted to that purpose although they were intended for a different function. Many years ago in going through the Rhone valley this point was vividly brought to my notice when I was shown certain turbines fed by water coming from the glaciers, and it was astonishing to see that that water, being aerated by free oxygen, was so corrosive that in a few months a cast-iron impeller practically vanished. We have therefore in the aeration of the condensate a very serious menace to the plant, and I am looking forward to the adoption of appliances to overcome this difficulty.

**Mr. W. B. Woodhouse**: There is much information in this comparatively short paper. The author's remarks with regard to constructional details are of particular interest in connection with large condensers. I am inclined to favour rather strongly the use of the cast-iron shell for large condensers, even though it is made in sections, because I have had a good deal of trouble with corrosion when cast iron was not used. The point the author makes as to reducing the friction losses through the condenser tubes is important, and up to the present has been rather neglected. The loss of head in passing through the water boxes and in and out of the condenser tubes is quite considerable and the suggestion of a special form of end plate and conical mouth-pieces to the tubes is a good one. I think we might go farther in big condensers and consider whether we could not direct the flow of water in the boxes by vanes much as is done in the casing of a centrifugal pump, to ensure that the water flows equally through all tubes, and so get a better result from the condenser. Some condensers certainly are not obtaining the full duty from all the tubes because the water is apt to "short-circuit" and the flow through some of the tubes is very little. The next point which appeals to me from the operating side is that of screening. Mr. Bailey has referred to his difficulties, and I think we have all had them; as a result of experience I have come to the conclusion that screening must be

done in stages. Unfortunately, even with the finest screen a good deal of scale-forming and sometimes greasy matter is deposited in the condenser, retarding very considerably the passage of heat through the tubes. To use very large turbines economically they should be kept running as continuously as possible, and stoppage for the purpose of condenser cleaning ought to be unnecessary. I see no reason why we should not so develop our designs that the condenser can be cleaned in sections while the turbine is at work. I am told that there are difficulties with regard to tube joints and so forth, but I think they could be got over. Some members doubtless know that vertical tubes with open ends have been adopted in some places. The top of the condenser being open, it is possible while the water is passing to clean the tubes with a brush. I believe the method works well, but it has certain obvious disadvantages. We want some means of cleaning horizontal tube condensers and maintaining them clean while they are at work. Scouring with sand has been tried with some success and I believe is quite effective, but special arrangements have to be made and there are possibly objections to the method. With the author's remarks on air allowances, I quite agree. He suggests that it would be a good thing to standardize the amount of air with which the condenser makers are asked to deal. I have not at the moment figures to compare with his, but I hope to communicate them to the *Journal*. I think we are all inclined to err on the top side so that the air pumps are too big. That brings one to the most interesting development of recent years in condensers, viz. air-extracting devices. I went into the matter in considerable detail about 5 years ago when there were three types put forward: the solid air pump, the liquid air pump in which the air was extracted by a jet or column or flakes of water, and finally the gaseous air pump in which steam was used to extract the air, and I came to the conclusion that it appeared to be inherently wrong to try to entrap air with anything but another gas; and that generally speaking the principle of extraction by steam jets was the right one. I have had some 4 years' experience of air extraction in this way and it has been wholly satisfactory, and I am glad to see that many condenser makers are now putting forward air pumps with steam-jet extractors. It is quite easy to check the steam consumption; one has only to see that the bore of the steam jets is kept constant. They are easily renewed, and they have the great advantage that their use does away with a piece of running machinery.

(*Communicated*): In the discussion I quoted certain figures of performance of steam jet extractors, which were questioned. I find on reference to the tests that the figures I quoted were incomplete and that the actual figures were as follows:—

| | |
|---|---|
| Weight of steam condensed per hour .. | 87,000 lb. |
| Vacuum .. .. .. .. .. | 97 per cent |
| Steam used by air extractor per hour: | |
| Primary jet .. .. .. .. | 258 lb. |
| Secondary jet .. .. .. .. | 438 lb. |

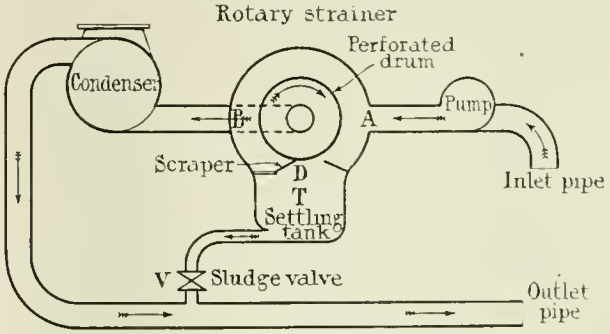
The steam from the primary jet was condensed and returned to the main condenser, that from the secondary jet passed to a feed heater. The apparatus was designed to extract hourly 35 lb. of air from 90,000 lb. of steam. Calculations of the partial pressures showed the air content in this quantity of steam to be 10·4 lb. A smaller extractor designed to deal with 25 lb. of air per hour from the same condensate used the following amounts of steam per hour:—

| | |
|---|---|
| Primary jet .. .. .. | 195 lb. |
| Secondary jet .. .. | 356 lb. |

Since the discussion Mr. A. C. Eborall has been good enough to send me particulars of a condenser which has been made for some years by Messrs. Brown, Boveri & Co., designed to permit cleaning in halves while in use. I am glad to know that the point I raised had already been met.

**Mr. G. W. Partridge**: Now that the turbine has been decided to be the most satisfactory prime mover for driving large generators the question of condensing becomes of great importance. There has been a great deal of loose talk lately about erecting super-power stations at the coal pits or at regular intervals all over the country, but I do not think that many of those who talk on the subject have taken into consideration the enormous amount of water which is required to get a good vacuum with these large turbo-generators. Generally speaking, every pound of coal burned requires about 500 lb. of circulating water. I agree with the author generally, but there are several points upon which I should like to make a few remarks. I agree, on page 441, that the ratio of the length of the condenser to its diameter should be as low as possible, and that the nearer this ratio is kept to 1·5 the better. My own experience of a large condenser which we have in use, with a cooling area of about 25,000 sq. ft. area, is a ratio of 1·56. I think the author's point of sub-dividing condensers so that they can be cleaned or examined without putting the main generator out of commission is very important. Mr. Woodhouse touched on the subject and I thoroughly agree with him. If possible I should like to see two condensers, but they would take up a considerable amount of room and might in some cases be impossible. It is difficult to estimate the most efficient speed of the circulating water through the condenser tubes owing to the large variation in temperature. For instance, on the Thames the temperature between summer and winter varies from 35° F. to 70° F., and the speed of the water in the pipes varies in our case from 3 ft. to 8 ft. per second, and the quantity of water from 40 to 120 times. I have been told by engineers in America that the speed of the water was in some cases never less than from 9 ft. to 10 ft. per second, and that it was kept at that speed in order to clean the condenser. Some years ago I heard of a generating station at which at certain intervals the vacuum improved without any apparent reason; it was eventually found that this took place when the ashes were unloaded. On looking into the question it was discovered that a certain amount of the ashes fell into the river and passed through the condensers, scouring them and thus improving the vacuum. The driving of station auxiliaries is a very important matter. The main points to be con-

sidered are the reliability of the supply, the reliability of the motors running for long hours without requiring attention, and the possibility of speed variations. In considering this subject we may assume that a certain number of auxiliaries would be steam driven; the question is which is the best system for the electrically driven auxiliaries. One has a choice of two systems, either direct-current or three-phase. If we assume that the drive is three-phase, this could be taken from a common three-phase low-tension system from the busbars with an alternative supply either from a separate transformer connected to each main generator with a throw-over switch, or from a small alternating-current generator driven off the shaft of the main alternator, or by means of a special alternating set capable of dealing with all the auxiliaries in the station with a suitable stand-by. On the other hand, if we assume that the drive is to be direct current this could be taken from a common direct-current supply given by rotary converters or motor-generators from the main busbars, with an alternative supply either from a special direct-current machine on the shaft of each main generator, or a suitable battery, or a special direct-current set large enough to drive all the auxiliaries, with suitable automatic change-over apparatus in case of failure in either of these supplies. I have had many years' experience in this latter arrangement at our Deptford station and it has worked admirably, but in spite of this I am of the opinion that for driving the main auxiliaries of a big power station it is preferable to use alternating current. This should be supplied from an independent three-phase set with an alternative supply from the three-phase busbars as I have described. Both these supplies would be normally connected in parallel with automatic means of disconnection in a case of failure of either supply. The smaller auxiliaries, such as fans, conveyer motors, and other apparatus which require variation in speed would be driven by direct current supplied from rotary converters or motor-generators, which in turn would take their three-phase supply from the three-phase busbars driving the main auxiliaries. Such a lay-out would have many advantages over the direct-current system, and would do away with the trouble with commutators and brushes in the larger motors. There would be no drop in speed if anything went wrong with the main generators, as the supply would be automatically thrown over on to the auxiliary set to which I have already referred. The author on page 443 deals with tidal and non-tidal rivers. For a non-tidal water I think the arrangements suggested, of the two large ducts with branches leading from the main duct in each pump, which is similar to the lay-out of St. Denis station in Paris, is the right one; but in connection with a tidal river I think a closed syphonic system carefully designed with ample facilities for removing air at suitable places, is the best. I do not altogether like the author's Fig. 4. It seems to me that if it were a system of any capacity, the pipes would be in all probability of 36 inches or 48 inches diameter, which would mean the operation of huge valves. I see no method of laying off either of the pipes which are dependent on the syphonic action, and the joints must therefore remain absolutely tight. It would be exceedingly costly in excavation and if the water were dirty I do not see how one would be able to clean or even to see the strainers. If the end of the pipe in the river became blocked up, even for a short time, I should imagine the syphon action would be lost altogether and there would be considerable trouble in starting up again. The best system for a tidal river appears to me to be the closed system. The author on page 445 refers to water strainers. Some years ago one of my assistants, Mr. Aitken, designed a strainer for working at our Deptford power station, and as the author appears to have never seen or heard of it I will endeavour by means of a sketch to show what it is like (see Fig. A). I believe there are about 15 of these strainers in continual use on the river Thames alone. These strainers are made with capacities of from 250,000 to 1,000,000 gallons per hour. The strainer is composed of a gunmetal perforated drum, which revolves at a speed of from three to four revolutions per minute.




*Not to scale*

FIG. A.

There is a scraper (D) of hard nickel bronze bearing against the drum over its whole length. The water comes in from outside at A and leaves the inside of the drum at B. Any solid matter settling on the outside of the drum is scraped off by the scraper which has a cutting edge and falls into a settling tank (T). There is a sludge valve (V) that is opened every hour, or every shift, or every day, depending upon the amount of sludge in the settling tank. When the valve is opened all the sludge is forced back into the river. The strainers have been working for a considerable number of years and have given absolutely no trouble. There is no leakage loss; they are suitable for a closed system, that takes advantage of the syphon action; they can be placed either on the suction or discharge side of the pump by a small modification of design. Four of these strainers have been in use on the suction side of the circulating pump and are giving every satisfaction. Other advantages of these strainers are that they are small, inexpensive, and take up very little room. There are two ways of operating such a closed system as I have described, either by means of (1) a circulating service of pipes, pumps and strainers to each unit; or (2) a common system for the whole generating station. I am of the opinion that this latter arrangement is more satisfactory as it enables the circulating

water to be better distributed to the condensers. The efficiency of the circulating pumps is kept high as they are nearly always running at full load, being suitably graded for the load of the station. Another great advantage is that the failure of any one pump does not affect any individual generator. Fig. B shows such a system in duplicate. By manipulating the main valves B, C, and D, any set of pumps can supply either side of the condensing system. The system I have described has been in continual use at our Deptford power station for a great number of years. Although our circulating pumps are driven by steam, direct current, and three-phase, their speeds are never varied as they are kept running at efficient loads, being specially graded for the load of the station.

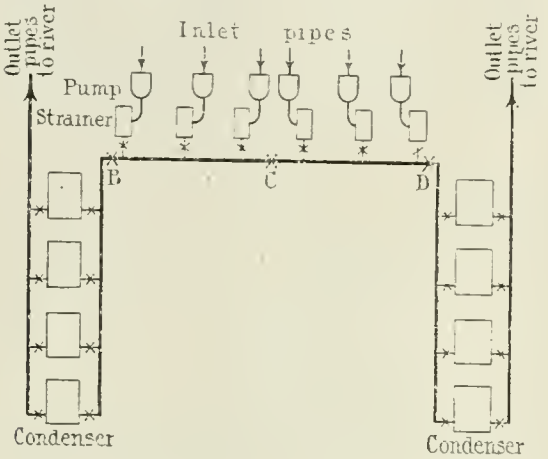



Fig. B.

(*Communicated*): During my visit to the Continent in 1913 I remember seeing in course of construction one or two large condensers designed, I believe, by Mr. Eric Brown of Messrs. Brown, Boveri, called "continuous service condensers." These condensers admirably fulfil the requirements suggested by me in the discussion of the paper as to the cleaning and laying-off without interruption of the supply. The condenser itself is divided into two parts in such a manner that one half can be cleaned whilst the turbine is operating on the other half. The temporary reduction in the vacuum due to this arrangement does not really make any substantial difference to the all-day efficiency of the plant. I was informed that the lay-out of the pipework is not at all complicated. The cost of such an arrangement is of course higher than the ordinary simple design of condenser, but I think it is money well laid out, especially when the installation of large size units is in view.

**Mr. E. R. Briggs**: A good deal of work has been done in recent years towards determining the rate of heat transmission, particularly in the United States. During the last six years or so the *Transactions* of the American Society of Mechanical Engineers have contained several papers on the subject. The difficulties of carrying out experiments in heat transmission are mainly due to the question of cost, because it is practically impossible to obtain, as the author has stated, satisfactory readings on condensing plants under average conditions of station operation. My firm (Messrs. Willans & Robinson) have recently obtained, through the kindness of the Dundee engineers, some figures which are as reliable as it is possible to procure, but the great disadvantage still remains of dealing with the variables, since it is impossible under actual operating conditions to separate the various factors and obtain readings of one variable at a time. The water velocity, for instance, has a great influence on the rate of heat transmission. The value usually taken is that the heat transmission varies as the square root of the velocity; but this is by no means certain. Reference has been made to the subject of the velocity of water through the tubes, and American practice of 8 ft. or 9 ft. per second has been quoted. Later information from the United States leads one to the conclusion that these very high velocities have been abandoned, and Mr. Orrok—one of the leading authorities in the States on condenser problems—has strongly recommended a velocity of not more than 5 ft. per second, since the extra gain in heat transmission is not worth the greatly increased cost of pumping the water. Another variable about which practically no informations exists is that of the air quantity. The experiments by Smith of Victoria (Australia) were all made with a small model, consisting of a single tube, with stagnant air and stagnant steam. The results obtained, therefore, have no bearing on actual condenser work. It is important to bear in mind that the actual quantity of air leaking into a condenser does not necessarily have a detrimental action on the rate of heat transmission, provided the air pump is large enough in capacity and can keep the partial air pressure down to the lowest possible limit. The author refers to the flow of water through the condenser and the amount of frictional losses in the water boxes. In some large condensers which my firm are now designing they have departed from the usual practice of attaching the water branches to the water boxes and providing a separate end cover, and have adopted instead the marine practice of carefully designing the water boxes of a shape to give a stream-line flow and so reduce the amount of frictional losses in this part of the condenser. The condensers in question are two-flow, consequently tubes can be withdrawn and cleaned from the opposite end of the condenser. The author's Fig. 4 has received a certain amount of criticism; it is only fair to bear in mind that this illustration is only diagrammatic, but I should like to draw attention to the fact that the author shows pipe lines for conducting the water from the source of supply. This is not good practice, and where large quantities of water are used the water should be led by means of a large open channel. One of the best arrangements is that adopted at Dalmarnock by Mr. Lackie. He takes the water from the Clyde by means of an L-shaped concrete structure which is run out into the bed of the river, so guiding the water into channels leading to large culverts which pass through screening houses with screens of the chain type. The channel is continued along one side of the main engine room, where

separate pumps force the water through the condensers into a corresponding channel the other side of the engine room which leads back to the river below the intake. The main objections to the use of pipes are, first, the difficulty—in many cases impossibility—of cleaning them, with the result that the frictional resistance increases enormously; and secondly, the losses which arise when several pumps suck from one pipe.

**Mr. I. V. Robinson**: I should like to ask the author whether it would not have been better to utilize what, I think, are fairly well-recognized symbols for the temperature of the inlet and outlet water and the temperature of the vacuum, steam, etc., because one has to exercise one's memory so much in trying to remember what his various symbols mean. On page 441 he gives a formula for the calculation of the mean temperature difference between the water and the steam, and I think that formula can be put in a way which is very much easier to remember, viz.

$$T_m = \frac{D-d}{\log_e (D/d)},$$

where, using the author's notation, $D = T_0 - T_1$ and $d = T_0 - T_2$. Reference has been made to the heat-transmission coefficient formula which the author apparently attributes to Hausbrand who worked out an enormous number of formulæ, but I do not know that he was the first to suggest this method of calculation. Until quite recently, no doubt 300 to 500 was taken as an average figure; but I know of plants that were working six or seven years ago with a constant of 800 to 900, and I have seen them as high as 1,000. About 16 years ago, I was interested in some experiments which were made, starting upon atmospheric condensers, and we got very high transmission coefficients on atmospheric work up to 700 or 800. We made some experiments on the effect of increasing the water velocity by inserting triangular laths into the tubes; they increased the head on the pumps enormously, but also increased the transmission coefficient. The head was too great, so that it was not practicable. The author refers to the ratio of length to diameter of the condenser. The manufacturer, I think, prefers to have that ratio as high as possible because the cost of the condenser increases far more with the diameter than with the length. Manufacturers prefer to have it 2 to 1, although we get better condensers with 1·2 or 1·3, some plants with a ratio of 1·2 giving excellent results. With regard to the question of cast iron or wrought steel shells, I think that is very largely influenced by the facilities of the manufacturers. I have seen condensers of 30,000 square feet, with a cast-iron shell, and it did not look to me like good engineering. If, however, we make a condenser of the same total surface with a steel shell, we get something which looks as though it were designed for a particular job and not as if it were a makeshift. Some firms have not facilities for handling large steel shells. If the firm making the condenser also manufacture large cylindrical boilers, or have a large constructional steel department, they will probably have facilities for making the shells. I will also allude to the question of single or twin condensers referred to at the end of the paper. There again I think the manufacturer will be very largely influenced by his shop facilities. I once saw a 30,000 sq. ft. steel condenser going through the shop; it was very ugly and interfered with everything in the shop, but if we have to ask them to make any one shell of double the size I do not know what would happen. I think the manufacturer would probably prefer in that case to have it in two different shells; it has the advantage of easier cleaning by shutting off the water from one whilst the tubes are cleaned out, and it has very considerable advantages from the manufacturer's point of view. I am not quite sure that if he were able to put a price on everything he did for the job it would cost him much more to make it in two than in one when we get to single condensers of upwards of 30,000 sq. ft. surface. I was very much impressed by the figure mentioned by Mr. Woodhouse as to the steam consumption of the steam ejector. Whilst 253 lb. of steam in a turbine would correspond to about 20 kw., possibly the Edwards pump would not take more than that, but we cannot always rely on the Edwards pump giving 29·4 inches of vacuum. There is no doubt that the steam ejector has made a good showing up to the present, and the fact that so many firms are developing it now, I think, is a good augury for its future improvement. I think the Edwards pump is practically out of date for large sets. With small sets in isolated stations, a long way from skilled assistance, it may be a good thing to have an Edwards pump, as everybody understands it. People cannot appreciate the great effect on steam consumption of frictional wearing of a nozzle, which originally was only 3·16 inches in dimeter; and when it increases 1·16 inch they do not think there is much in it; but there is a lot in it when we come to pass steam through it. I think it would have been of more use if the author had given the figures in Fig. 3 as a formula. The air capacity which has to be allowed for a large condensing plant will be reduced enormously in the future. I know many plants where they put in duplicate air pumps, each capable of dealing with 60 per cent of the anticipated aggregate air capacity of the plant. They have usually found that one of the pumps was quite sufficient to run the whole plant, and have never had to use the second pump. That showed that they were very much over-estimating the air requirements. I also think that, as time goes on, we shall enormously reduce the quantity of air below what we find to be the case now. I would call particular attention to a system which I have heard called the "closed circuit" system of feed water. I believe that it was considered very closely by the engineer of one of the large municipal stations in this country, and he is practically embodying it in his new plant. The point to aim at is the prevention of the feed water coming in open contact with the atmosphere anywhere. If we consider the ordinary path of the condensate from the condenser to the boiler, we very often have it in the open air through some type of water-measuring apparatus. This is not necessary, as there are water meters of equal accuracy of the totally enclosed type which are quite suitable for large quantities of condensates and are not expensive. There is also another open point on the circuit, the reservoir between the condensate

discharge and the boiler feed-pump section. It is practically impossible to eliminate that point, but its air-absorbing capacity can be reduced very considerably by allowing the condensate pump to discharge into a header from which the boiler feed-pumps would draw. On the upper side there would be two or three small connections to a surge tank, which would provide for the absorption of the condensate supply in excess of the boiler feed-pump requirements at any particular moment. Water in contact with air is bound to take up air, but I do not think that with the above arrangement the quantity taken up would be serious and we should eventually get the air capacity of the plant reduced enormously and, I believe, we should be able to use the steam jet ejectors with even greater advantage than at the present time.

**Mr. C. C. Paterson**: In connection with the use generally of smooth-bore tubes for the circulation of cooling water, it is not always realized that the moving column of water in the tube passes through almost as if it is solid. The outside layer becomes greatly heated whilst the centre of the column remains practically cold. We found this when constructing water-cooled resistance tubes. In a $1\frac{1}{4}$ inch tube 18 inches long for the same water velocity the cooling was practically the same whether an inch solid rod was fixed at the centre of the tube leaving only $\frac{1}{8}$ in. space, or whether the full unrestricted bore was left. By roughening the surface of the rod, however, so as to impede the smooth flow of the water the cooling was very much more efficient, the difference in temperature between the two ends of the tube being hardly perceptible, whereas before there must have been a difference of some 50 degrees C.

**Mr. S. B. Donkin**: There is one point which I think nobody has criticized so far in the paper, and it is referred to in Fig. 2. The author compares there a counter-current with a parallel-flow condenser, and he shows that at varying heads he gets an increased saving of power with the parallel-flow type; but he states at the beginning that we must assume that the syphonic efficiency varies from 100 per cent at zero head to 75 per cent at 34 ft. head. I think it ought to be pointed out that in any big power station it is essential to maintain the syphonic efficiency of 100 per cent, and one does that at an expenditure of very little power. One knows from practical examples that it is possible to maintain 100 per cent syphonic efficiency, say for a 5,000 kw. station, with an expenditure of about 0·5 per cent of energy. With either system, when maintaining 100 per cent syphonic efficiency, the head against which the pump works is the same. I mention the point because the diagrams and the explanation are very attractive but are a little apt to lead one to assume that the parallel-flow system has something in it which the other has not. So many speakers have criticized the system of collecting water in tidal waters that I think it is hardly necessary to say anything on that subject, but I should like to say that it is extremely desirable, or at any rate we have found it so from experience, to be able to use the change-over system and to have enough pipes into the source of the water to allow the changing over to be done without stopping. In order to get rid of any silt or accumulation in a pipe, it can be discharged through that pipe at twice the velocity at which the water is taken in. If we have a system with three pipes, and always suck through two and discharge through one, we have that condition met. The only time that the condition is not met with is when we are changing over from one pipe to another and sucking through one and discharging through one. I think it is desirable to endorse what has been said as to the closed system of circulating water being the better one, as in my opinion it enables a pump to boost up the velocity of the water, which cannot be done with a system of open chambers. With open chambers we can only allow the natural difference in head, or the difference in head created by the pump, to boost up the supply, and we are limited by the dimensions or height of the suction pits.

**Mr. J. C. Wigham**: In a case I am connected with, where fairly large condensers are in use, the great trouble we have had is with mussels, and if any member can tell us how to get rid of them we shall be glad to hear of it. We are, unfortunately, bound to use cast-iron pipes across the river and as far as the circulating pumps, the obstruction of mussels in the course of a year is quite serious. At present we arrange to shut down one day in the year, and by means of steel ropes draw a cutter through the suction pipe to get rid of the mussels. Out of a pipe 300 yards long and 20 inches in diameter we take from half a ton to a ton of mussels a year. After we have started up again we fill the whole of the strainers with dead and broken mussels in the course of a few minutes, and men have to be constantly employed for some hours in opening one strainer and shutting down the other before the mussels can be got rid of.

**Mr. J. Christie** (*communicated*): The author on the last page of the paper refers to the corrosion problem. This is one of the most serious and far-reaching troubles with which power users who have to use sea water or water contaminated by acid or sewage effluents in their circulating system have to contend. The Fourth Report of the special Corrosion Committee of the Institute of Metals was issued last month and contains a great deal of most useful information and deals with experiments with Admiralty mixture tubes which were carried out under the supervision of their investigators at Brighton. The conclusions arrived at, so far as present knowledge goes, seem to favour the electrolytic system of protection as the surest and best known means of eliminating this trouble, and pending the discovery of an incorrodible alloy at a reasonable cost, I consider this system of protection will for the present more than fully justify its general adoption. High efficiency of an expensive condensing plant is entirely neutralized if it has to be frequently shut down to locate and replace defective tubes, and our experience at the Southwick power house, which works under shipboard conditions, has proved conclusively that the trouble can be controlled and overcome by the electrolytic system of protection. In my opinion the root cause of the trouble is graphitization of the cast-iron water ends of the condenser. This flakes off,

and in contact with the non-ferrous metals composing the tubes, tube plates and ferrules, in conjunction with the seawater as an electrolyte, provides all the elements for setting up most active corrosion. Local pitting and perforation of the tubes then takes place, fouling the condensate, which, in turn, sets up corrosion in the economizers and boilers. When the density increases, priming starts, and the corrosive water is thus carried through to the superheaters and turbines, causing corrosion of the tubes, blading and shrouding. At Southwick we had a condenser installed eight years ago. In four years it had to be re-tubed three times, involving the scrapping of some 10,000 tubes. Four years ago we put in the Cumberland electrolytic system of protection and have since practically eliminated all our trouble. A second similar condenser installed four years ago also had the system fitted to it from the very start, and up to date we have not had a single tube failure. Careful and independent investigation of sample tubes which have been withdrawn from time to time for inspection shows that the average life of the tubes, which, under our conditions—unprotected—may be taken at something less than 3 years, is extended to some 20 years. To ensure successful application, it is essential that the tubes, tube plates, and ferrules, should be properly bonded, that they should be coupled to the negative pole, that the current density be regulated to a suitable amount, and that the insulated anodes be regularly inspected, cleaned and renewed at suitable intervals. If the system is applied right from the start as part of the original equipment, this primary cause of all the trouble, viz. the flaking off of graphitized parts of cast iron, will be absolutely prevented. The cost of installation and maintenance, compared with the value of the plant that it protects, is a very small amount to pay for the advantages and freedom from worry which it undoubtedly ensures.

**Captain E. H. Cockshott** (*communicated*): With regard to the cooling water required for condensing purposes, I think the author's figure of 8 degrees F. to 9 degrees F. rise in temperature in passing through the condenser tubes is too small. In order to limit the temperature rise to the figures given it will be necessary to provide a ratio between the amount of water and steam of 120 to 1, which is excessive and would be very difficult to provide for in the case of large stations. I am of the opinion that if the allowable temperature rise of the circulating water is between 11 degrees F. and 13 degrees F. satisfactory results would be obtained, the latter figure being equivalent to a water-steam ratio of about 80 to 1. The question of the amount of water for condensing purposes required at large stations is of course a very serious matter, and the provision of a suitable circulating water system usually causes considerable difficulty; it is therefore necessary to provide that the amount of circulating water supply is not excessive. Apart from this, the amount of water handled by the circulating pump affects the power absorbed by the pump. The circulating pump in many cases absorbs about 3 per cent of the total generator output, and therefore the total coal value of the power thus absorbed is a considerable yearly cost, which becomes excessive unless due care is taken in the design of the circulating system. It is the common practice to provide for three or four passes in the condenser, but I am of the opinion that in most cases equally good results could be obtained from the condensing point of view if these were reduced. In the case of a 15,000 kw. set which I have in mind the total power absorbed by the circulating water pump is nearly 500 h.p., and of this 190 h.p. is solely due to the friction of the condenser tubes. I do not think it has been definitely proved by reliable tests that the proportion between the length of water passage between inlet to outlet, and the diameter of the tubes adopted to-day in modern condensers, gives the best results, and I would suggest that if the total length were reduced, that is by putting more tubes in parallel and reducing the number of passes, equally good results would be obtained with a beneficial effect in respect of a reduced power for the circulating water pump. This would of course reduce the velocity of water flow, but I do not think that any appreciable adverse effect upon the cooling capacity would result. In very extensive tests carried out by the Government during the War on apparatus the duty of which compares in many respects with the surface condenser, viz. cooling devices employing water passing through tubes and cooled by air flow over the outsides of the tubes, it has been established that the velocity of flow through the tubes had very little effect on the rate of heat transmission between the water and the external medium. The material factor governing such problems is that the heat dissipated or absorbed by the water tubes to or from the external medium is proportional to the difference in temperature between the external medium and the mean temperature of the tube surface. I believe that the question of turbulence of the water passing through the tubes has been exaggerated in the case of condenser tubes where the ratio-length to bore is necessarily great; and that experiments would show a considerable saving in power required for the circulating pump could be effected by lowering the water velocity through the tubes resulting from a reduction in the number of passes now usually employed. It is usual to provide tubes of $\frac{3}{4}$ inch diameter, but as super-power stations will generally be built so as to take the circulating water from a river, a large amount of floating or suspended matter and rubbish in the water will have to be dealt with. It is necessary to consider carefully whether the usual size of tube would not prove troublesome under service conditions due to frequent blocking. Although screening arrangements will necessarily be provided so that an abnormal amount of cleaning will not be called for due to obstruction in the condenser tubes, I consider that in order to reduce the ill effects resulting from stoppages due to blocked tubes, more satisfactory results would be obtained by using tubes of not less than 1 inch in diameter. Hard and fast rules for tube surface cannot be laid down on account of the varying conditions. It is necessary to provide sufficient surface so that under summer conditions when the temperature of the water is a maximum and with a reasonable degree of tube dirtiness the required vacuum can be main-

tained. If the tube surface is only sufficient to maintain the required vacuum when the tubes are in clean condition, then, under working conditions, the vacuum will suffer when the tubes are covered with dirt and an unnecessary number of stoppages will be incurred for cleaning purposes. In the case of large sets using river water for circulating purposes, in this country it is suggested that a suitable surface to provide is 1 square foot of tube surface per 6 lb. of steam dealt with per hour; this provides a much greater surface than is usually recommended by manufacturers, but is necessary to meet adverse conditions which frequently occur in practice. The author says very little regarding the question of pressure drop across the steam space. It would appear that in most cases the resistance to steam flow through the condenser is much too great, resulting in an excessive pressure and temperature drop. With satisfactory designs a pressure drop not exceeding 0·1 inch of mercury should be obtained, corresponding to a theoretical temperature difference between top and bottom (allowing for no air present and 29 inch vacuum) of 3 degrees F. This cannot of course be obtained in practice; the temperature difference between the top and bottom of the condenser being usually from a minimum of 10 degrees F. and upwards, but which could be suitably improved upon largely by reducing the resistance to vapour flow through the condenser. Regarding counter-current and parallel-flow arrangements, I do not think the figures shown by the author of savings of head across the circulating pump resulting from the adoption of parallel flow can be substantiated; the only material difference, so far as the circulating water pipes are concerned, between the two arrangements is that the absolute pressure at the highest point of the water system will be greater in the case of the parallel-flow arrangement. The chief reason for the adoption of the counter-current system is of course that a given condensing capacity can be obtained with a lower amount of tube surface (in the region of 12 per cent) than would be the case with the parallel-flow system. An objection to the usual counter-current system (where dry air pumps are used) is that the condensate formed in the upper part of the condenser drips over the lower and colder rows of tubes, and is thus unduly cooled before passing to the condensate pump. The temperature of the condensate leaving the condenser is frequently many degrees lower than should be the case and is chiefly due to over cooling by the lower tubes; with large machines the value of the heat loss thus incurred is quite an appreciable item. It would be an advantage if arrangements could be made so that the water of condensation could be drained away near the points of formation in the condenser, and it may be possible by some such arrangement to obtain a gain of at least 5 degrees F. and upwards in the temperature of the condensate. The coal value of this in the case of a certain 15,000 kw. set, on the basis of 6,000 hours' running per annum and coal at £1 per ton, is over £300 per annum.

In view of the present high prices for coal it is interesting to compare the energy costs for running the different types of plant put forward by various makers. It will be found that the annual running costs in respect of rotary types of air pump are quite an appreciable item for very large sets, the greater part of the power being absorbed in circulating the water through the jets adopted for entraining the air. If, however, the extraction pumps are driven by steam turbine and it is practicable to make use of the heat returned by the exhaust steam from the turbine by means of a feed-water heater, the running costs could then be appreciably reduced. The higher feed-water temperature would also reduce the tendency to corrosion of the economizer tubes. Steam jet-type air pumps show a very low annual running cost, taking into account the value of the heat given to the feed water. Regarding the amount of air to be dealt with, I am inclined to agree with the author that Fig. 3 shows a reasonable estimate of the free air due to both feed-water absorption and leakage, but for normal running conditions only. For large turbines the amount of air to be dealt with is now commonly taken as 5 lb. per 10,000 lb. of steam, this allowing for the air dissolved in the feed water and also for leakage under normal conditions; this allowance agrees with the author's curve for turbines consuming 250,000 lb. of steam per hour upwards. To make Fig. 3 clearer, the words "per 1,000 lb. of steam" should be added to the words "lb. of free air." As the efficiency of a surface condenser very largely depends upon the effective removal of air from the condenser, it is necessary to provide that the capacity of the air pumping plant is ample to meet the conditions of abnormal air leakage. For rotary systems the capacity must therefore be such that a satisfactory vacuum will be maintained in cases where the air leakage is excessive, and therefore under normal conditions the power required for driving purposes will be excessive. With the steam jet type of plant, however, it will be desirable and is a considerable advantage in the case of large sets to arrange for the air pumping plant to be split up into three or four separate units so that the number of jets to suit the conditions at any time can be put into operation, thus effecting considerable economies in annual running costs. As future large power stations will in most cases be built on a river site it will be necessary to make special provision for screening the circulating water. In many instances this has proved a very difficult matter, and much thought has already been devoted to this subject in connection with existing large generating stations. It will be necessary in many cases to provide for dealing with very large quantities of rubbish and floating matter which may amount to some hundreds of tons per annum, the majority of which will have to be dealt with during the autumn when leaves and floating vegetation is carried by most rivers in large quantities. It is thought that moving endless strainers made up of wire-gauze panels will meet most requirements, and these can readily be cleaned either by the water-jet gear mentioned by the author or by revolving brushes such as have been in operation for a number of years with satisfactory results at Lot's-road power station, Chelsea. For the above reasons the arrangement shown by the author in the elevation of Fig. 4 would not be suitable. Strainers of an adequate area could not possibly be

provided by such an arrangement; no automatic means for cleaning are provided and they would therefore rapidly become clogged in most situations. In the same view the pipe leading from the river to the circulating water pit is of the syphon type. With this arrangement rubbish would be lodged in the top portion of the pipe, and at this part an objectionable air pocket would also be formed. This would restrict the water passage and increase the head lost in a pipe of this description, resulting in an excessive drop between the river level and the circulating pit which, in the arrangement shown, would at some time or other allow air to pass into the circulating system with disastrous results. The strainer pit should be connected to the river by either totally submerged pipes or by an open channel. A valve should be provided in order that the pit may be isolated from the river for cleaning-out purposes, this process being chiefly necessary as considerable quantities of mud will collect in the pit, due to the latter being preferably arranged of large size so as to reduce the water velocity and thus operate as a settling tank.

**Mr. S. F. Walker** (*communicated*): The construction of the surface condenser has been almost revolutionized since the advent of the steam turbine. Before that time it was a canon of the steam engineer's faith that it was uneconomical to employ vacua higher than 25 inches, and in some cases, such as those of steamers passing through tropical waters, 20 inches was often the limit. All that has now been changed; turbine makers called for high vacua, and Sir Charles Parsons led the way in showing how these should be obtained, and proved that high vacua were certainly economical with the steam turbine. Makers and users of reciprocating engines have also discovered that high vacua are economical; and there are many cases in this country and abroad where compound and triple-expansion engines are working with vacua of $27\frac{1}{2}$ inches and occasionally 28 inches. Of course this result has been largely due to a more careful investigation of the conditions of condenser efficiency. The reciprocating engine itself has been improved; the steam passages between the cylinder and the condenser have been designed so that the steam is no longer throttled on its way to the condenser. In the latest forms of steam turbine and steam condenser, this arrangement has been carried probably to its limit. Again, the condenser itself has been greatly improved, and the important departure has been made of withdrawing the condensate and the air by separate pumps. Arrangements are also made to drain off the condensate as soon as it is formed, so as to avoid the possibility, which was very much in evidence in the older condensers, of re-evaporation taking place if the pressure of the steam entering the condenser was lowered, say, by a sudden lessening of the load on the engines or turbines. I gather that the author is of the opinion that the surface condenser will predominate in the future; I do not think there can be much doubt about that, except in very special cases. Properly arranged, the surface condenser nearly realizes one of the dreams of the steam engineer; it returns to the boiler nearly all the water that was originally converted into steam in the boiler. This, of course, means economy. A point that has struck me very forcibly in my study of the condenser problem is the important effect of the varying capacity of water for dissolving air. The ability of water to dissolve air varies directly as the pressure forcing the air into the water, and inversely, though not in the direct ratio, as its temperature. The lower the temperature of the water and the greater the pressure to which the air is subjected, the larger is the quantity of air the water will dissolve. I think that this property accounts very largely for the striking success of the Edwards air pump. The condensate, having to run over the colder tubes at the lower part of the condenser before reaching the pump, is cooled, and is able to dissolve more of the air than it otherwise would have done. This led to the production of what were thought to be high vacua in those days, because of the fairly complete abstraction of the air; but, as the author has pointed out, it also led to trouble in the boiler, from the presence of air in the condensate. As steam engineers know to their cost, air always gives trouble in the boiler; and the later forms of condenser in which the air is carried off by a separate pump should lead to higher efficiency in the boiler due to less trouble from this cause. The solution of air in water has, however, another effect; it raises the temperature of the water. According to the theory of modern chemico-physics when air or any gas is dissolved in water or any liquid, the gas is reduced to the liquid form, and in so doing gives up its latent heat to the liquid, raising its temperature. I believe I am correct in saying that in the Leblanc air pump, which works with a closed water circuit, small slices of water dissolving small quantities of air, this trouble has been experienced, the water of the closed circuit rising in temperature. The rise in temperature of the water in this case would lead to a lowered efficiency of the pump; the small slices of water being at a higher temperature dissolve smaller quantities of air, and so the abstraction of air from the condenser is lessened and the vacuum lowered. In some of the other forms of rotary pumps that have been introduced since the Leblanc, this difficulty has been met and overcome; doubtless the makers of the Leblanc pump will also find means of overcoming it. This question of the solution of air in water also affects the make-up for the boiler feed. As is well known, there is always some loss of water between the boiler and the hot-well, even with the most perfectly designed and most carefully worked plant; and this has to be made up from an outside supply. If the water from which this is taken is exposed to the atmosphere, the quantity of air dissolved in the make up will vary with the time of year and the barometric pressure. In very cold weather with the high barometer which we sometimes have then, the quantity of air dissolved will be comparatively large; whilst in hot weather, with a low barometer it should be the reverse. It may be said that the make up for the boiler feed is so small that it does not matter; but with the super-power stations we are to have, even the make-up may be considerable in quantity; and it may easily be increased by want of care with the condenser plant, or by bad design. So important is the matter considered

to be, that even the hot-wells of some steam plant are carefully closed in, as nearly air-tight as possible, so that there shall be as little danger as possible of air reaching the water in the hot-well and being dissolved. There is also another factor in the condenser problem which is worth the attention of those who are interested in the matter. The capacity of air for absorbing the vapour of water practically for mixing with the vapour, varies rather rapidly at the temperature of the steam entering the condenser with vacua of 25 inches and thereabouts. The curve showing the relation between the capacity of air to absorb the vapour of water, and its own temperature, rises very rapidly, in the neighbourhood of 100° F., and above. The capacity of air for absorbing moisture increases with its temperature ; it rises rather slowly with comparatively low temperatures, but very rapidly above 80° F. I think this would have a bearing upon the working of the condenser. If, for instance, a rather large leak of air occurred and the temperature of the air reached the figures given above, its capacity for absorbing the steam and carrying it off by way of the air pump would be increased ; so that the condensate would be lessened and the blanketing effect mentioned by Sir Charles Parsons some years ago would be increased. The whole study of the temperatures of the condensate, of the steam, and the air and pressure in the condenser is worth careful consideration. It will perhaps be interesting to note that a surface condenser has been introduced in America, apparently with good results, in which the usual arrangement is reversed : the steam enters at the bottom and leaves at the top, the cooling water entering at the top and leaving at the bottom. The size of the condenser tubes is also a matter deserving very careful attention ; water is a poor conductor of heat, and therefore it is only the skin of water on the surfaces of the tubes that has really any useful effect ; that is why a higher velocity is beneficial. It is also the reason why the evaporative surface condenser is so efficient ; it only uses a skin of water for cooling.

**Mr. R. J. Kaula** (*in reply*) : The arrangement shown in Fig. 4 has been the subject of much criticism but, without touching for the moment on the adequacy or otherwise of the strainers proposed, it appears to me that most of the speakers have overlooked one important factor. The scheme is intended to be applied where the difference in level between the water at low tide and the power station site is such as to involve a big suction lift on the pumps if they are placed on the ground level. Cases naturally arise where the difference in level exceeds the possible suction lift of a pump. Where a large suction lift exists at all we should be faced with two most undesirable alternatives, either to let the unstrained water pass through the pumps or to place the strainer on the suction side and under vacuum, which is undesirable in itself and further limits the possible static suction head on the pump. As regards the syphon pipe shown, the sketch is simply diagrammatic and in a large power station it would probably be preferable to run two or more pipe lines in parallel. It has been suggested that such syphon pipes might get blocked up and that a leaky joint might spoil the syphon and consequently stop the flow of water Exactly the same thing applies to any pump suction.

One or two of the speakers appear to have overlooked the fact that the scheme as shown gives a completely syphonic circuit between the pumps and the discharge circuit. I was certainly unaware of the progress made in the design of revolving strainers. If these can be built in suitable sizes and with the small leakage loss named by Mr. Bailey, they should certainly take the place of the arrangement of strainers and valves indicated in the diagram. Mr. Briggs goes so far as to condemn the use of pipes entirely for these conditions, but the only alternative is to construct open channels to the full depth, and the cost of this would be quite prohibitive if carried over any distance.

Mr. Bailey raises the very important question of standardizing condensing plants. Unfortunately the varying conditions of load factor and cooling-water temperature to be dealt with make it very difficult to go very far in this respect. If we are to compete successfully in foreign markets for turbine contracts we shall have to build small and moderate-size plants for stock. There is no great difficulty in building turbines and alternators to an advanced state to meet the more common steam conditions and voltages, etc. ; but it is useless doing so unless a suitable condensing plant can be shipped at least as early as the remainder of the plant. The condenser auxiliaries can generally be completed in a comparatively short time, but the construction of the condenser shell itself involves a longer period. Taking for instance a 5,000-kw. plant and cooling water at 60° F., one might safely assume that a vacuum of $28\frac{3}{4}$ inches would meet most requirements. The same condenser would maintain a vacuum of 27·7 inches with inlet water at 80° F. or, again, it would give a vacuum of 29·1 inches with cooling water at 50° F. It will thus be seen that a stock condenser can be adapted to a wide range of conditions. The figures given here, however, are chosen at random, and it would be well if makers could agree on a definite relation between vacua and cooling water temperatures for standard sizes of turbines. Purchasers would no doubt be prepared to accept reasonable suggestions in this respect if they could thereby ensure better deliveries. I should like to suggest that the turbine corrosion which Mr. Bailey noticed where glacier water was in use might reasonably be ascribed to the large quantities of pulverized stone which such water usually contains.

I am particularly interested in the figures which Mr. Woodhouse has kindly supplied giving the performance of two steam-jet extractors. I think that the credit is due to him of having adopted this type of ejector on a large plant for the first time, and the figures now published are, I believe, the first operating test results available for air pumps of the steam ejector type. The results are certainly very satisfactory, and indicate a marked improvement in economy over results obtained with other pumps. The Brown Boveri type of continuous service condenser mentioned by Mr. Woodhouse and several other speakers is the type I had in mind in referring to designs of this description.

The type of strainer shown by Mr. Partridge is certainly new to me. Personally I think it preferable to feed each condenser from its own pumps and through separate pipe lines, rather than arrange the whole of the system on omnibus pipes. I am rather surprised to note that Mr. Partridge prefers alternating-current drive for his auxiliaries to direct-current. The loss of the possibility of obtaining speed regulation seems to me a big sacrifice; whilst I agree that the arrangement which he proposes should serve its purpose, in the case of failure of a main generator it does not appear to get over the difficulty of the drop in main turbine speed due to a rush of load.

The Dalmarnock lay-out referred to by Mr. Briggs is in line with that advocated in the paper for non-tidal rivers, but it does not appear to lend itself in any way to tidal conditions.

I agree with Mr. Robinson that the method of notation which he advocates is preferable in many respects to that used in the paper. I think he is inclined to underestimate the importance of keeping down the ratio between condenser diameter and length. He mentions the difficulty of handling a condenser of 70,000 sq. ft. in the shops. Personally I think that a condenser of that size should be built up on the site; in any case the railway gauge is such as to make this necessary in the majority of cases.

If, as Mr. Donkin states, it is possible to maintain 100 per cent syphonic efficiency the advantage claimed for parallel-flow condensers over counter-current condensers is certainly reduced, but my experience has shown such an efficiency to be the exception rather than the rule.

I think that the chief advantage to be claimed for parallel-flow condensers when used on syphonic systems is not so much the actual saving in power but rather the general advantage of having a lower syphonic vacuum to account for, and in the case of comparatively low differences of levels it will be seen that the syphon is done away with entirely. This again facilitates the circulating pump design for the reasons set out by Mr. Selvey.

I regret that I do not know a remedy for the trouble which Mr. Wigham has experienced due to the growth of mussels.

Mr. Christie has been so intimately connected with the latest research on the subject of tube corrosion that his remarks are of particular value. I agree with him as to the primary cause of the trouble and I believe that in many cases this can be eliminated by careful painting of the water boxes.

Captain Cockshott has evidently confused the temperature rise of the water with the difference between outlet temperature and vacuum temperature. I agree with him that two-pass condensers are generally preferable to three- and four-pass condensers, especially since the friction losses in the water boxes and at the tube inlets and outlets form such a large proportion of the total condenser friction loss.

I cannot agree that it is advisable to lay down a hard and fast rule for the proportion between tube surface and steam quantity since the ratio is entirely dependent on steam and water conditions, and any figure so determined would necessarily give an excessive margin in some cases and too small a margin in others. I think that the only sound means of providing against a fall of vacuum due to fouling of the tubes consists in allowing a percentage margin on the calculated surface. I agree that the question of steam-pressure drop across the condenser deserves full attention, but it is exceedingly difficult to obtain reliable data on the subject. I do not think that the majority of modern condensers show a drop much in excess of the figure advocated by Captain Cockshott. I am glad to have his agreement with the values put forward in Fig. 3 for air quantity under normal conditions. Personally I am of the opinion that it is better to have an indication of an abnormal air leak which can usually be traced and stopped without much difficulty, than to provide against this in the shape of an excessively large air pump, which will be wasteful in power consumption under normal conditions of running. I think that whatever system of strainers is adopted it is important to introduce a reversal of flow in the inlet and outlet pipes to prevent silting, etc., at the pipe inlets. The syphon pipes shown in Fig. 4 are, of course, intended to obviate the necessity of building totally submerged pipes or open channels, which would be exceedingly costly where the power station site is at a considerable height above low-water level.

The temperature rise in a Leblanc pump referred to by Mr. Walker is, I believe, essentially due to condensation of vapour and friction losses in the pump itself. This temperature rise is not peculiar to the Leblanc pump and applies to practically all forms of rotary air pumps, and it is the reason for providing amply dimensioned water tanks with automatic arrangements for the supply of cold water and the withdrawal of hot water.

## South Midland Centre, at Birmingham, 26 March, 1919.

**Mr. R. A. Chattock**: The paper does not in my opinion emphasize sufficiently the extreme importance of reliability in connection with the condensing auxiliaries. As far as I can gather, the author recommends one circulating pump for each unit, driven either by a steam turbine or by an electric motor. Whilst I agree that it is perhaps safe to use one circulating pump if sufficient spares are carried, I certainly think that the driving of this pump should be in duplicate, as there is much more chance of breakdown on this portion of the apparatus. Should a breakdown occur on the circulating pump, the turbines will almost immediately go over to atmosphere, and on this account it is of vital necessity to provide against breakdown as far as possible. I am of opinion that the best arrangement to adopt is to put in two circulating pumps, each of about 60 per cent of the full load capacity, and to drive one of these by a steam turbine and the other by an electric motor. Both pumps would be run, and should one break down, the other could carry

the load with a reduction of only 1 inch to 1½ inches in the vacuum. The amount of steam used by the small turbine is also not excessive, and the whole of the latent heat in it can be recovered by heating the condensate before it is returned to the boilers, instead of some being wasted, as is the case with a turbine of full capacity. In regard to the air pumps, water extracting and lift pumps, as these are small and inexpensive there is no objection to putting them in in duplicate and each of full capacity. Also, as their stoppage through breakdown is not of serious importance for a few minutes, it is safe to risk driving them entirely by electric motors. I do not agree that alternating-current motors should be put in for this purpose. The speed variation that is obtainable with direct-current motors makes this method preferable; also with alternating-current machines there is another link in the chain to go wrong, and the possibility of a temporary stoppage is increased should anything fail on the main alternating-current supply. As regards the air pump, I rather favour the steam ejector type of pump, as there are no running parts in this to get out of order, and it has been demonstrated that very high vacua can be carried with a proper arrangement, whilst the whole of the latent heat in the steam used can be recovered. Another advantage is that it is a simple matter to de-aerate the condensate and the make-up feed water by means of these ejectors, and so obviate the serious difficulties that are being experienced through the presence of excessive air in the feed water, which causes oxidization in the feed pipes and boilers. The description given by the author of straining the circulating water is interesting, but I think that with most river waters it will be found that the strainers will very soon become choked up. My experience is that in connection with the Thames this took place in about an hour to an hour and a half, and it is obviously impossible to keep reversing the flow of these large pipes as frequently as this. I consider that the revolving self-cleaning strainer is the best apparatus to get over difficulties of this kind, especially as it is possible to fit this in a closed circuit system. Such a system is very necessary where the water is tidal, as at low water with an open system the power taken by the circulating pumps is very largely increased over the conditions at high water, whilst if the system is closed and all air extracted from it, the pump simply acts as an impeller in the circuit and the power taken remains constant whether it is high or low water. The saving in power so effected counterbalances any loss there may be in short-circuiting a portion of the water through the strainer. The complications and difficulties that are experienced due to it being necessary to strain river water are a distinct point in favour of using cooling towers in connection with the condensing plants, where the quantity of make-up water required does not amount to more than one gallon per kilowatt-hour generated. It is of course a simple matter to strain a small quantity of this kind, compared with straining the total quantity of circulating water, which is from 70 to 100 times as great. In connection with this matter I should like to emphasize what a very valuable asset a big industrial city has in the filtered sewage effluent that is running to waste wherever its sewage is treated. In Birmingham we have demonstrated that this effluent is even more suitable for surface condensing than ordinary water, as we find that the tubes and interior of the condenser are kept perfectly clean, there being no scale formation whatever. Reports from our Medical Officer prove that the aeration of the water in the cooling towers immediately kills any sewage bacteria that may remain in the water after it has been passed through the filter beds, so that there is no risk whatever in using this effluent for the purpose. There is sufficient sewage effluent running to waste in Birmingham within three miles of the city boundary to provide amply for a generating station of one million kilowatts capacity, should this ever be required in the district. The nearest river of any size is the Severn, and this is 20 miles away, whilst the summer flow of water in this river is only capable of providing circulating water sufficient for a station having a capacity of about 100,000 kw. without the use of cooling towers. To provide a natural flow of water for 10 such stations would necessitate going very much further away from where the supply of electrical energy is required, and this would mean a corresponding increase in the loss through transmission and in the burden of the cost of the transmission lines. I maintain therefore that all large industrial centres should look very closely into the possibilities of utilizing their filtered sewage effluent, which can readily be obtained close to the industrial demand for electrical energy, and so save the heavy cost of transmission from a distance.

**Mr. W. M. Selvey:** In Table 1 the author has partially dealt with heat balance for a condenser, but his fourth column is not the H of formula (1). I have for about the past 10 years made a hobby of determining water quantities by the heat balance of a condenser. The original commercial demand arose out of the desire to make certain of the performance of a circulating pump after it had been connected up, the pump being supplied by one contractor and the condenser by another. In those days there was very little existing information on condensers compared with the huge mass which is now available. This latter has come about due to the attention given to the subject arising out of the new types of air pumps which have been developed during these 10 years. In the hope that it may be useful to some other members I have taken the author's Table 1 and, adopting columns 1, 2, and 3, have worked out what I should expect to be the balance sheet under modern conditions for the three different vacua of 28, 28½, and 29 inches. These values are extraordinarily well chosen if they were intended to illustrate progress made in turbines during the last 10 years. It is hoped, however, that some of the largest turbines running under the conditions of line 1 may realize as high as 85 per cent efficiency at the turbine coupling. Under all these extreme conditions of steam and vacua it will be seen from the Tables * which I have prepared that the actual value

* Owing to the limited space available only one table (see Table A), namely that for 200 lb. pressure, is here reproduced, but the calculated values of the "heat to circulating water" for this and other pressures are summarized in Table B.

of H in formula (1) is extraordinarily constant, it being practically unaffected by vacuum for a given set of conditions, and very little affected by the higher efficiency gained with improved steam conditions and size. In understood that when considering each case on its merits some attempt will always be made to calculate these losses definitely. It will, however, be noted what considerable variation can occur in their values

TABLE A.

*200 lb. abs. Pressure, and 200 degrees F. Superheat.*

| Case | Callendar | | | Marks and Davis | | |
|---|---|---|---|---|---|---|
| | (a) | (b) | (c) | (a) | (b) | (c) |
| Pressure, lb. per sq. in. (abs.) | — | 200 | — | — | 200 | — |
| Superheat, degrees F. | — | 200 | — | — | 200 | — |
| Saturated temp., ° F. | — | 381·8 | — | — | 381·9 | — |
| Total temp., ° F. | — | 581·8 | — | — | 581·9 | — |
| Vacuum (30 in. bar), in. | 28·0 | 28·5 | 29·0 | 28·0 | 28·5 | 29·0 |
| Vacuum temp., ° F. | 101·1 | 91·7 | 79·0 | 101·2 | 91·8 | 79·1 |
| Total heat ($H_0$), therms per lb. | — | 1317·1 | — | — | 1307·7 | — |
| Available work, therms per lb. | 383·5 | 398·1 | 418·1 | 379·6 | 394·6 | 413·6 |
| Realized at 75 per cent efficiency at turbine coupling, therms per lb. | 287·6 | 298·6 | 313·6 | 284·7 | 296·0 | 310·2 |
| At alternator terminals 96 per cent efficiency, therms per lb. | 276·1 | 286·7 | 301·1 | 273·3 | 284·2 | 297·8 |
| Turbine consumption at alternator terminals, lb. per kw. hour | 12·37 | 11·91 | 11·34 | 12·49 | 12·01 | 11·47 |
| Heat allowances for 2 turbine bearings, therms per lb. | — | 1·5 | — | — | 1·5 | — |
| Heat loss from casing, therms per lb. | — | 3·0 | — | — | 3·0 | — |
| Carried off by condensate, less 5° F. condensate loss, therms per lb. | 64·1 | 54·7 | 42·0 | 64·2 | 54·8 | 42·1 |
| Heat and work extracted from the system, therms per lb. | 356·2 | 357·8 | 360·1 | 353·4 | 355·3 | 356·8 |
| Heat to circulating water, therms per lb. | 960·9 | 959·3 | 957·0 | 954·3 | 952·4 | 950·9 |

TABLE B.

*Heat to Circulating Water, in therms per lb.*

| Case No. in author's Table I. | Pressure (abs.), lb. per sq. in. | Superheat, ° F. | Callendar Vacuum (30 in. bar) | | | Marks and Davis Vacuum (30 in. bar) | | |
|---|---|---|---|---|---|---|---|---|
| | | | 28 in. | 28·5 in. | 29 in. | 28 in. | 28·5 in. | 29 in. |
| 1 | 300 | 250 | 946·0 | 943·7 | 940·5 | 938·7 | 936·6 | 934·2 |
| 2 | 200 | 200 | 960·9 | 959·3 | 957·0 | 954·3 | 952·4 | 950·9 |
| 3 | 150 | 100 | 948·1 | 947·5 | 946·5 | 944·0 | 943·0 | 943·2 |
| 4 | 150 | 100 | 965·2 | 965·2 | 965·2 | 961·5 | 961·2 | 961·8 |
| 5 | 14·7 | — | 982·6 | 982·7 | 982·8 | 982·1 | 982·3 | 982·6 |

preparing the Tables I have used conventional figures for the loss in the bearings, the heat loss from the casing, and the alternator efficiency. These figures are of about the right order, but it will be readily

without very much affecting the value of H. As regards the measurement of $T_1—T_2$, this really calls for something more than the ordinary arrangements if its accuracy is to be of the same order as that of H.

When faced with actual cases I had made a set of thermometers of a type having a very large bulb, long stem, and very open scale embracing not more than about 10 to 15 degrees F. Such thermometers can be read with ease to 1/100th of a degree, and provided they are accurately calibrated and continually checked against a standard to ensure that they are in order, there is no reason to doubt the measurement of $T_1—T_2$ as a temperature difference. There is more reason, however, to doubt whether the quantity measured as $T_2$ is really the average temperature of the water leaving the condenser, as with a slow flow there is a tendency for the water to form into layers with hotter water on top. It is well, therefore, to have a thick-walled copper thermometer pocket extending right across the pipe and also to take this measurement as far as possible from the condenser as can be done without introducing other difficulties. The author also draws attention to the fact that the specific heat of water is not unity, but I think we can afford to neglect this. There are three standards of specific heat of water which have been adopted from time to time: the first of these is the 15° C. calorie which equals 4·184 joules, the Callendar or the 20° C. calorie which equals 4·180 joules, and the mean calorie which equals 1/100th of the heat to raise one gramme of water from 0° C. to 100° C. which equals 4·185 joules. Messrs. Marks and Davis's tables are based on the mean therms which correspond to the mean calorie. The mention of these tables calls to mind that the author has been a prominent member of the B.E.A.M.A. Committee through whose good offices the Moss-Callendar tables have been developed. I should like to take this opportunity of pointing out the differences that are likely to arise between using these and the Marks and Davis steam tables which previously were fast becoming the standard tables used by turbine designers and testers. Some suspicion has been thrown on the values for the specific heat, and consequently the total heat of superheated steam as used in the Marks and Davis tables. While I cannot go into the controversy between the pure physicists as to the reliability of experimental data as compared with the use of a rational formula, it is rather to be regretted that in superseding for some purposes the Marks and Davis tables some effort should not have been made to prepare a set of tables on similar lines. The Callendar steam tables though giving the necessary information give it in such a form as to make it laborious to abstract and, what is of more importance, less likely to be abstracted correctly by a busy man who wants a quick reference at hand. I may therefore express my hope that the good work of the B.E.A.M.A. Committee may be further extended so as to add to the Heat Drop Tables all the other steam properties used in calculation in the same British units. I also append three tables (one of these, Table C, is reproduced herewith; the other two relate to tests on a 5,000-kw. turbo-alternator and a small turbo-alternator respectively) of actual tests showing a condenser balance taken at various times during the

TABLE C.

*Test of Turbo-Alternator Rotary Combination.*

| Load | ½ | ¾ | Full | 1¼ |
|---|---|---|---|---|
| Condensed steam, lb. per hour | 31,252 | 39,844 | 50,609 | 63,106 |
| Steam consumption of turbine, lb. per kw. hour (direct current) | 14·49 | 14·04 | 13·42 | 13·69 |
| Deduct air pump vapour (as not condensed in condenser), lb. per hour | 126 | 205 | 218 | 200 |
| Net steam condensed in condenser, lb. per hour | 31,126 | 39,639 | 50,391 | 62,906 |
| Inlet circulating water average corrected temperature, ° F. | 59·55 | 60·4 | 63·0 | 60·5 |
| Outlet circulating water average corrected temperature, ° F. | 69·54 | 72·4 | 74·7 | 74·4 |
| Rise of temperature of circulating water, ° F. | 9·99 | 12·0 | 11·7 | 13·9 |
| Heat per lb. of steam entering turbine, therms | 1297·4 | 1292·1 | 1208·1 | 1290·2 |
| Heat extracted per lb. of steam as appearing at d.c. terminals, therms | 235·7 | 243·2 | 254·4 | 249·4 |
| Efficiency of rotaries, per cent | 91·5 | 92·5 | 94·0 | 94·5 |
| Efficiency of alternator, per cent | 90·5 | 93·5 | 95·0 | 95·5 |
| Allowance for turbine bearing friction, per cent | 2·0 | 1·3 | 1·0 | 0·8 |
| Product of these three efficiencies | 81·12 | 85·35 | 88·39 | 89·52 |
| Heat extracted by turbine blades per lb. of steam, therms | 290·5 | 284·9 | 287·8 | 278·6 |
| Condensate, ° F. | 72·7 | 76·9 | 80·0 | 79·8 |
| Heat carried away in condensate (reckoned above 32° F.), therms | 40·7 | 44·9 | 48·0 | 47·8 |
| Radiation losses (expressed as per lb. of steam passed), therms | 6·5 | 5·1 | 4·0 | 3·2 |
| Heat carried away by circulating water, therms | 959·7 | 957·2 | 958·3 | 960·6 |
| Circulating water, gall. per min. | 4,983 | 5,269 | 6,879 | 7,246 |
| Surface of condenser, sq. ft. | 5,800 | 5,800 | 5,800 | 5,800 |
| Heat transmission coefficient, therms per deg. F., mean temp. diff. per sq. ft. per hour (K) | 428·5 | 410·7 | 477·5 | 475·3 |
| Actual vacuum attained, in. (abs.) | 0·92 | 1·11 | 1·26 | 1·39 |

last 5 years. In the case of the 5,000-kw. turbo-alternator the values of K were as follows :—

| Load | ¼ | ½ | ¾ | Full | 1¼ |
|---|---|---|---|---|---|
| K | 233 | 330 | 340 | 375 | 389 |

and of the 1,500-kw. set

| | | | | | |
|---|---|---|---|---|---|
| K | — | 251·9 | 466·2 | 488·3 | 613·7 |

In calculating the value of K I have never yet found it necessary to use the logarithmic formula, and I doubt whether it is ever much used. There is no practical difference between the two values until one comes to cases where the steam temperature very closely approaches the outlet temperature. This never occurs in the ordinary two-flow condenser with large tubes and low velocities, such as is popular at the present time, but with high velocities and for four-pass condensers such as have been used to some extent on the Continent it is perhaps necessary to use the logarithmic formula. I have come to the conclusion that the value of K, other things being equal is very closely connected with the steam friction drop across the condenser, partly because the heat transference conditions are better at the surface, but still more because any appreciable steam friction tends to spread the steam and make the whole of the surface active. I have made some very elaborate experiments on three-pass condensers which gave striking results in this direction. The principal thing, however, which could be learnt from them was the fact that on low loads only about one-third of the surface is in action, the rest of the tubes being "air drowned." As the load comes on the boundary between the steam and the air is lowered towards the bottom of the condenser, and at overload it has been taken pretty well down to the throttle where part of the condenser is baffled off and maintained as an air cooler. While for a given condenser K will rise with the velocity of the water I do not find that this is in any way a determining function for obtaining a high vacuum. Sufficiently good vacua can be obtained with quite a moderate velocity and consequent low friction drop on the water side. The value of syphonic action is rather overstated. Modern efficient centrifugal pumps take practically the same power at all outputs, and since the pump has to throw the water over the top of the condenser to start up there is very little diminution of power when the syphonic action is established. Arrangements can of course be made for using a pump which will not give the necessary lift for starting up by using an air pump to exhaust the water side, but my experience has been so much against anything of this nature that I always recommend such pumps to be installed in such a manner that the water flows naturally to the pump and that the water circulation is self-restoring should any accident occur or due to faulty manipulation. I rather regret that some attempt has been made to return to the Edwards type of air pump in connection with an augmentor. It is true that this is still the lowest in power of all systems and is a robust arrangement. The power, however, taken by other purely rotary pumps is not now much greater than the augmentor combination if strict account is taken of the steam which is actually used in the steam jets. As regards air in the feed water introduced by any type of air pump, I am not yet certain that water can be really de-aerated even under conditions of moderately high temperature and vacuum. Moreover, if the air which is liberated in an economizer does not at first come out of solution in contact with a surface under pressure strain, there is no need to anticipate any troublesome corrosion in a boiler due solely to air. The author's curve of Fig. 3 is, as far as I know, the first time when such data have been put forward as a standard for agreement. The object of such a curve is, I take it, that it shall be agreed what is the necessary size of air pump for a given plant, and also forms a basis for testing the air pump as to its air-extracting properties on the workshop test-bed. In the practice with which I have been connected it has been usual to look for a much bigger margin in the air pump than this curve represents, but the feeling to-day seems to be to install twin air pumps, each of which could be of the capacity indicated by the curve, so that in case of an air leak the second pump could be started up. The pure steam-jet type of pump is very good as an auxiliary to the ordinary efficient air pump, but it is not possible to use the steam from such a pump economically if the feed pump is steam driven also. If the circulating pump is also steam driven there will be a considerable waste of steam unless these auxiliaries exhaust against a back pressure into the main turbine. Of course if economizers are not used then a considerably larger quantity of steam can be absorbed by the feed water, but there is still an excess for an ordinary size plant having all steam auxiliaries.

TABLE D.

*Possible Vacuum with certain Condensing Water Temperatures.*

| Condensing Water, Temperature ° F. | Vacuum Temperature = Producible Pressure (abs.) | | Approximate Vacuum with 30-in. Bar |
|---|---|---|---|
| | ° F. | In. | |
| 40 | 62 | 0·560 | 29·6 |
| 50 | 72 | 0·790 | 29·2 |
| 60 | 82 | 1·098 | 28·9 |
| 65 | 87 | 1·289 | 28·7 |
| 70 | 92 | 1·508 | 28·5 |
| 75 | 97 | 1·759 | 28·25 |
| 80 | 102 | 2·045 | 28·0 |

As regards cooling towers, there appears to be very little common knowledge as to what towers can be made to do. This is owing to the fact that the trend of commercial competition, combined with the very cramped circumstances of our older power stations, has led to the use of towers which are remarkably inefficient from a vacuum-production point of view. No reason whatever is given why in a new lay-out with ample room a mean yearly temperature of 70° F. could not be maintained at the base of a tower. Table

D shows the possibilities with modern first-class condensing plant with water of a given temperature, and I would comment on this as follows: Tidal waters on the East Coast of England have an average temperature well below 50° F., and therefore the vacuum can be reduced with such water far and away below what any large turbine can be commercially built to utilize. There are considerable difficulties even at a size of 15,000 kw. to make a turbine take full advantage even of 29 inches, and when the designs of some machines which are now being constructed are published it will be seen what unusual arrangements have been made to deal with it. At a 30,000-kw. size there is very little question but that 28·5 inches is quite as low as can be economically provided for. It can of course be done by using two shafts with a double-flow low-pressure turbine running at a moderate speed, but this so adds to the capital cost as to make it uneconomical commercially to construct except for excessively large units. The conclusion I have derived from these considerations is that with these larger sets having modern condensing plant and a first-class lay-out of cooling towers, all the vacuum can be obtained which is necessary to the highest overall commercial efficiency.

**Mr. G. R. J. Parkinson**: There is one point regarding which I should like to ask the author's explanation. I do not see how the heat rejected is less than the latent heat of the exhaust steam, particularly as where the turbine is overloaded or the low-pressure blading is not very liberally designed I am inclined to think the exhaust steam is actually superheated. I should also like to ask the author if he can refer to any actual tests showing the increase in heat transmission due to higher velocity of water through the tubes. I have never made any experiment on condensers, but I made a careful test on a Green's economizer to test the effect of increasing the velocity of water through the tubes. The economizer was divided into three sections all in parallel. I re-connected the economizer with the three sections in series, but although this increased the velocity in the ratio of 3 : 1 the final temperature was the same as with the sections in parallel. The experiment was carried out long enough to get a fair average reading, although it was impossible to guarantee exactly the same conditions: unless the increased efficiency due to high velocity is very marked the extra cost of pumping against the increased friction is a serious consideration. With regard to the author's suggestion for cleaning the scale from condenser tubes with hydrochloric acid, I have found this a very dangerous proceeding if the tubes are cleaned *in situ*. The acid has a serious effect on the cast-iron water bonnets: after cleaning a condenser two or three times in this way I examined one of the hand hole doors. This had been machined on the inside and the tool marks were still clearly visible, but on scraping the surface with a knife I found I could cut it away for a depth of nearly $\frac{1}{8}$ inch. The iron had disintegrated, leaving a mixture of graphite and finely divided iron. As continued cleaning with acid would have seriously weakened the casting and the tubes were hopelessly scaled I removed the tubes 100 at a time and pickled them separately with acid. This method was entirely satisfactory but a somewhat expensive process.

**Mr. F. Forrest**: Referring to Fig. 1, if W lb. of water are to be cooled from $T_2$ to $T_1$, then $W(T_2-T_1)$ heat units must be given up. Assuming that cooling towers are being used, the whole of these heat units will be expended partly in raising the temperature of the air passing up through the towers, and partly in evaporation, and if we know the relative humidity of the external atmosphere and of the heated air where it leaves the top of the towers, we can calculate very closely the quantity of water evaporated under given conditions. With the average conditions prevailing in Birmingham at the present time, this evaporation amounts to approximately one gallon of water for every unit generated, and this figure gives the quantity of make-up water which is required for the cooling-tower ponds. I am glad that the author has given prominence to the question of standardizing air-pump capacity, although I cannot agree that the curve shown in Fig. 3 is one that is likely to prove acceptable to purchasers. The usual figure of 0·8 lb. of air per 1000 lb. of steam rejected to the condenser might be used as a reasonable basis for turbine plant working under average modern conditions, and if some such figures as this was generally agreed to, then the condensers and the air pump could be tested together with calibrated air nozzles attached to the condenser casing to demonstrate that the air-pump capacity was easily capable of dealing with the normal quantities of air likely to be present. I am quite with the author in thinking that the actual figure which is to be standardized is not of very great importance so long as some figure is generally and universally agreed.

**Mr. P. R. Boulton**: On page 441 the author states that the value of K varies distinctly with the cooling water velocity. He does not, however, discuss the effect of the steam velocity on this figure. I am aware that the effect of the steam velocity on the coefficient of transmission is rather a difficult one to express definitely, and in practice it is further complicated by the varying percentage of air which is carried over at varying loads owing to the leakage. This is still further complicated by the varying degree of dryness, to which the author draws attention, since obviously at the higher loads the lower tubes are partly engaged in cooling the water which has been condensed by the upper tubes. In testing condensers, I am convinced that the methods of taking temperatures by inserting thermometer pockets at one point or the inlet and outlet pipes is not sufficiently accurate, since stratification takes place and the water leaves the condenser in layers of different temperatures, and to obtain the average, either a number of pockets should be inserted, or a tube made of high conductivity metal should pass diametrically through the centre of the outlet pipe. One end of this tube should be sealed to prevent air circulation, and the bulb of a thermometer having a very long stem should contact with the inside of this tube by means of metal foil, and in this way the temperature can be taken at different points. The author points out that errors are sometimes introduced in calculations owing to the fact that the specific heat

of water is not constant. I should have thought, however, that this figure was sufficiently constant for all practical purposes within the range of temperatures usually employed. I do not think that the author has sufficiently emphasized the importance of efficient air extraction. The performance of a given condenser varies enormously with the efficiency and capacity of the air extraction pumps. With regard to the water velocities usually employed in condensing plants, I am inclined to think that the commercial economy of many modern plants would be improved by adopting a lower velocity, with consequent reduction in pumping charges, and installing an increased condenser surface in order to obtain the same vacuum. Further, in view of the fact that one rarely finds condensing plants operating with a minimum difference between steam and water temperatures of 10 degrees, and bearing in mind the enormous reduction in cooling-tower costs which can be effected by pushing up the top temperature a few degrees, it would appear to be more economical to employ a larger condenser in order to reduce the minimum difference between steam and water to, say, 6 or 8 degrees. This would necessitate a somewhat larger condenser, but less cooling tower surface would be required. The combined cost could be reduced, inasmuch as the cost of cooling towers per kilowatt is considerably more than the cost of condensers. Another effect, which the author does not mention, and which would operate in favour of the adoption of a lower minimum difference, is that of the higher rate of transmission per degree difference at higher water temperatures, this being presumably due to the greater molecular activity of the water. The relative advantages of steam or electric drive for auxiliaries is one on which engineers do not agree. The advocates of electric drive give as an argument in favour thereof the fact that when sufficient economizer surface is installed the full use cannot be made of the exhaust steam from the auxiliaries for feed heating. On the other hand, the advocates of steam drive contend that it is much better to ensure reliability in the operation of the auxiliary machinery in the case of failure or interruption of the supply, and this argument I consider to be a very strong one. Usually, when an interruption of supply occurs, the engineer-in-charge has quite enough to do, without the additional anxiety as to what is happening to the condensing plant. In reply to those who contend that the efficiency of the economizer is reduced when the feed is preheated by exhaust steam, owing to the higher average temperature of the water which would obtain were the outlet temperature the same as if no preheating had taken place, I would say: Reduce the economizer surface, so saving capital expenditure, until the final water temperature is commercially the most economical. With regard to the relative merits of rotary hydraulic and ejector systems of air-pump extraction, I have in mind that it has been established by experts in these matters that the line of demarcation where the efficiencies of the two systems as regards power required are equal is at about 28 inches of vacuum, beyond which the hydraulic pump is the more efficient; but on this question the author's opinion would be valuable.

**Mr. F. F. P. Bisacre**: In formula (2), the author gives the usual logarithmic formula for the cooling surface S. $T_m$ is the temperature difference between the inside and outside of the tubes, and may be assumed to apply over the whole surface S, i.e. it is the equivalent temperature difference rather than the mean temperature rise. It is important to have clearly in mind the conditions assumed in the formula and to which therefore it applies. The tubes are assumed to be in a steam space of temperature $T_0$ throughout, and the cooling water is supposed to be warmed up continuously from its inlet temperature $T_1$ to its outlet temperature $T_2$. Under these conditions, the surface given by the formula would be the same whether contra flow or parallel flow were assumed. It would be interesting to see data as to the actual distribution of temperature throughout the steam space. Is it nearly uniform or not? If it is nearly uniform, then, from the point of view of heat conduction, it is difficult to see the advantage of contra-flow circulation; if it is not, then Hausbrand's formula can only be a rough approximation to the facts. In any case, it is usually unnecessary to use Hausbrand's formula, with its complicated logarithmic factor. If $T_0$ is the steam space temperature, supposed nearly constant, $(T_0-T_1)$ is the temperature difference at the inlet end and $(T_0-T_2)$ at the outlet. The mean temperature difference is therefore $\frac{1}{2}(2T_0-T_1-T_2)=T'_m$ say. This is the value of $T_m$ which arises from the first term of a rapidly converging expansion of the logarithm in Hausbrand's form. The second and higher terms can safely be neglected, especially as K is not known with great accuracy, and the numerically simpler and obvious form can be employed. As to the value of K, there is experimental evidence that it is a very definite function of the water velocity V. When K is plotted against V, the curve resembles a B/H curve. There is at first a slow rise in K, corresponding to the preturbulent state; then a rapid rise within the region of turbulence and, when turbulence is fully established, further rise in K with increasing velocity is slow. The critical region varies with the kinematic viscosity of the fluid and the dimensions of the tube, as Osborne Reynolds' experiments show. Difficulty in transmitting heat is often experienced in oil coolers, in spite of the fact that the oil passes through the tubes at speeds between 5 and 10 ft. per second. This is perhaps due to the great difference in the kinematic viscosity of oil and water and its effect on the speed necessary to develop turbulence. As to Dalton's laws, it must be borne in mind that these laws refer to statical conditions; for instance, the conditions which obtain when a mixture of air and water vapour, say, are in equilibrium with water. This state of equilibrium takes time to attain. The phenomena taking place in a condenser usually proceed quickly. It is questionable if there is sufficient time for states of equilibrium to be attained. The effect of the time element in modifying the conditions of the formation of vapour have long been recognized by physicists and have recently been dealt with by Martin* in their bearing on steam turbine theory. So far as I know, it has not yet been studied

* *Engineering*, 1918, July 5 and 12.

in special relation to condenser problems. One case arises in the problem of air dissolved in the condensate. Elaborate precautions have sometimes been taken to prevent air from getting into contact with the condensate. The condensate is used over and over again, with the air-extraction plant working. It will thus be freed from entrained and dissolved air after the plant has been running some time. If, then, precautions are taken to prevent extraneous air coming in contact with the condensate, the latter should remain air-free —and an air-free pure water is generally regarded as the ideal boiler feed-water. When no special precautions are taken, water usually contains about 2 per cent of air. Experiments made on samples of condensate taken from a closed system showed about 1·5 per cent of air; so that there still remained about 75 per cent of the "normal" air content. The fact appears to be that water, when air-free, has a strong avidity for air. This avidity seems to fall off rapidly as air is absorbed, so that the absorption of air by initially air-free water rises exponentially with time. In a comparatively short time, 50 per cent of the "normal" amount of air may be absorbed, although it may take a long time for the absorption to become practically complete, but this is a point on which complete data appear to be lacking.

**Mr. R J Kaula** (*in reply*): Mr. Selvey's figures for H are certainly more nearly correct than those given in Table I, but he too shows a maximum difference of 4 to 5 per cent over the range of conditions chosen, and this difference should not be lost sight of in estimating the quantity of cooling water required. His remark as to methods to be adopted and precautions needed in taking cooling water temperatures are to my mind most valuable. The assumption of unity specific heat is, as he points out, near enough for all practical purposes, in so far as temperature is concerned, but if it is realized that average sea water has a specific heat of about 0·95 it will be seen that the possible error due to the consistency of water is not entirely negligible. I must join issue with him in his view on the subject of syphonic head. Personally I consider that it is important to take full advantage of any possible saving in head that can be secured by syphonic action. I agree that the pump should be capable of delivering water against the full static head for starting purposes or in case of failure of the syphon, but the quantity which needs to be delivered when working against this head needs only to be a small proportion of the normal. The characteristic of the pump should be such as to meet this condition, and even if this entails a slight loss of efficiency—as it is likely to do if the syphon head is a large proportion of the total—then the net power consumption will still be far lower than where the pump is designed to deliver the full water quantity against the full head, i.e. where no attempt is made to obtain a syphon effect.

The question of the effect of steam velocity on heat transmission coefficient in condensers raised by a number of speakers is a complex one, as it is so much wrapped up with that of air extraction. There is probably little doubt that a very high value of K can be obtained with high steam velocities, but it is hardly practicable deliberately to introduce the necessary drop of pressure in order to obtain such velocities. On the other hand the additional auxiliary power consumption due to raising the water velocity from, say, 3 to 5 ft. per second in the tubes is generally slight in comparison with the saving in condenser surface obtainable without loss of condenser margin. Nor should it be overlooked that a moderately high water velocity gives a certain scouring effect on the tubes and prevents fouling to some extent.

I am glad that Mr. Selvey and Mr. Forrest, together with other speakers, appreciated that I put forward the curve in Fig. 3 as a suggested standard only. I am well aware that far greater air allowances are frequently specified. Yet it is probably correct to state that in the case of the majority of turbine plants purchased no specification is given for air quantity at all, and the air allowance is left in the hands of the turbine and condenser makers with perfectly satisfactory results. I believe that in most of such cases the air allowance is within the limit set out in Fig. 3, and I therefore feel that it will be a mistake to standardize on figures very much in excess of those given, as suggested by some of the speakers.

If Mr. Chattock will refer to the third paragraph on page 444 of the paper he will see that I used almost the same words as himself in emphasizing the importance of reliability of the circulating water pump. But I think that duplicating of pumps and their drives entails so many complications, especially of pipe-work and valves, that one feels reluctant to go far in this direction. As regards the question of alternating versus direct-current drive, may I suggest a further reference to the paper, as Mr. Chattock will find himself again in agreement with what I have said. The suggested use of sewage effluent is most interesting, and I believe that a somewhat similar scheme was adopted at Edinburgh some 12 years ago.

Regarding Mr. Parkinson's remarks, the steam leaving a turbine is almost invariably wet. Many tests have been carried out which show the effect of water velocity on heat-transmission coefficient, and I may refer him especially to those published by Professor Weighton. As regards the use of hydrochloric acid, it seems to me to be simply a question of careful sluicing after its use in order to avoid such occurrences as that referred to by the speaker. I have known this practice to be adopted in many instances without any detrimental effect.

I have dealt with most of Mr. Boulton's and Mr. Forrest's remarks in replying to previous speakers. It would be hard to give a definite line of demarcation in the matter of power consumption when comparing reciprocating and rotary air pumps, but I agree that 28 inches may be taken as the limit for reciprocating pumps rather on the ground of capital cost and bulk.

I agree in the main with Mr. Bisacre's remarks on the subject of formula (1). It is probably quite reasonable to ignore the logarithmic formula. But as it stands it is easy enough to handle, and where it is in frequent use it has been worth while preparing sets of curves which give $T_m$ for varying conditions without reference to Tables. His statement as to the experiments carried out for the determination of air contents in water are of the greatest interest. I think that the whole question of aeration of water and its effect on boiler corrosion should be thoroughly investigated.

# DISCUSSION ON "THE FUNCTIONS OF THE ENGINEER: HIS EDUCATION AND TRAINING."*

SCOTTISH CENTRE, AT EDINBURGH, 11 MARCH, 1919.

**Professor Hudson Beare:** While agreeing on the whole with the proposals which the author has made, I perceive some practical difficulties in putting the scheme into operation. The initial difficulty is that of finding time in an already overcrowded curriculum for these new courses. At Edinburgh University, as at most of the British universities, the period of training for a degree in engineering is 3 years. The first year is devoted almost exclusively to training in pure science and mathematics in order to lay a foundation for the more purely technical work of the second and third years. It is necessary to devote a whole year to this preliminary training in science and mathematics owing to the unfortunate fact that so many boys come up from school badly trained in mathematics and with very little knowledge of any physical science. As a result of this arrangement the remaining 2 years which have to be devoted to technical work are very crowded, the student's whole time being taken up every day from early in the morning until late in the afternoon. The vast amount of original investigation which has been undertaken during the last 25 years in such subjects as the strength of materials, hydraulics and thermodynamics has led to a great increase in the number of hours which have to be allotted to these subjects during the training of a younger engineer, hence year by year the curriculum has grown more and more crowded and the difficulty of introducing new subjects has become almost insuperable. If the curriculum could be extended over 4 years much of this difficulty would disappear. Certain of the courses which the author would like to introduce could be taken up in the third year, and the remainder during the fourth year. The addition of a fourth year to the period of training would also allow teachers to deal more adequately with certain technical problems than it is possible to do at the present time. Another criticism which might be made of the proposals set forth by the author is that the period allotted to some of the courses is too short. It is difficult to see how a course extending over only 36 hours could be utilized to give an adequate training in certain of the subjects in the schedule of the paper. My practical experience as a teacher has convinced me that it is not advisable to shorten courses unduly. The more brilliant students are able to absorb new knowledge quickly, but the average student requires more time if he is to get more than a mere smattering of a subject. Edinburgh University could probably introduce some of the suggested new courses without very great difficulty in regard to the question of provision of teachers. The University has recently established a degree in commerce, and in connection with this new degree a new professorship and new lectureships have been established in such subjects as accountancy, business methods, administration and other subjects, all of them essential to the training specified by the author. As soon as the new scheme for the degree in commerce is in active operation, there would not be great difficulty in arranging that these new professors and lecturers should give special courses to technical students, such as engineers and chemists, dealing with the business side of their professional work, but, as already stated, such a scheme can only be carried out if the ordinary course is extended to 4 years. The difficulty in regard to this expansion of the course is the difficulty of convincing the average parent that it is necessary to give such a length of time as 4 years to university education. The average parent for obvious reasons is anxious to shorten rather than to lengthen the period of training—the period during which they have to maintain their sons. Parents with families of boys are naturally anxious to secure that the older members are in a position to earn their own living before the younger boys come on for their educational training. It has long been recognized and realized that in medicine the original length of the course was insufficient and it has been extended now to 5 years, and, if the engineer is asked to devote 4 years to training for a profession quite as important to the nation as the medical profession, I do not consider that we are asking anything unreasonable. The author has given most interesting particulars in the Appendix to the paper as to the relative importance of various qualifications needed by certain grades of officials in two types of engineering undertakings. I notice that in a tramway undertaking the chief engineer, and therefore the highest technically trained man, estimates that only 40 per cent of his value is that due to technical work, the rest being made up of administrative and similar work. These figures show how important it is for a young man who wishes to rise in his profession to realize from the outset that these extra subjects suggested by the author are not put into the curriculum for the sake of window-dressing but in order to turn out a young engineer better qualified to rise to the higher posts in his profession, and, if the author secures his object, he will have accomplished a great deal for the advancement of engineering. As regards the question of pupilage or apprenticeship, we have not experienced in Scotland to any great extent the premium trouble. In England, for many years at any rate, it was customary to exact the same premium for pupilage from a young fellow who had gone through a complete curriculum at a technical college or university as was paid by a boy straight from school. Such pro-

* Paper by Lieut.-Colonel W. A. J. O'Meara (see pages 225 and 315).

cedure was poor encouragement to any lad to take a full course of instruction in a technical institution. Our friends across the Atlantic realized long before we did in the old country that any such procedure as that just referred to was preposterous in the extreme. I have talked over the question of the practical training of young engineers with many American engineers and engineering professors, and I have heard on all sides that there is no difficulty in the United States in providing practical training for the young college student. At the end of every academical year the American university authorities always find there are more applications from engineering firms for young university graduates ready to begin their practical training than there are applicants for training. The question of carrying on simultaneously the practical and theoretical training is one which has been dealt with by several methods. Mr. Andrew Carnegie on one occasion asked my opinion as to whether it would be feasible to carry out the training in the following fashion: each student to spend one week in the college and then one week in the works alternately throughout the whole year. Such a system, of course, would involve the entire cessation of all academical holidays and would mean a serious increase in the number of the staff, as it is obvious that members of the staff must have regular holidays to recuperate themselves and must have a certain amount of leisure time for continuing their own education. Science is always advancing, and the only method by which a teacher can keep himself abreast of this advancement is by continual study. The engineering world looks to the professors and teachers of engineering to carry on scientific investigation and to widen the sphere of knowledge. If the teachers are to do this work as well as their ordinary teaching duties, it is obvious that a system such as that suggested by Mr. Carnegie would lead to great practical difficulty. Moreover, it is very doubtful how far engineering firms would agree to have a number of young men in their works putting in only alternate weeks in the shops. The other system for securing simultaneous training, which has been commonly known as the "sandwich" system, —the method of spending the 6 winter months in the university and the 6 summer months in the workshop —is a more feasible scheme and has certain merits. The total course of training would probably have to be extended to 5 years. There is no doubt whatever that the student during the later years of his training would derive more benefit from his college work if he had already become familiar with workshop practices and with practical problems which have to be faced day by day by the engineer. In conclusion I should like to state that one of the subjects outlined by the author, namely, the preparation of estimates and writing of specifications, is already, on the advice of the Institution of Civil Engineers, part of the routine training at Edinburgh and, I believe, at other universities which provide training for young engineers.

**Captain J. M. Scott-Maxwell**: The crux of the matter is the parents' view of what a boy should study at the university. The people of this country do not pay sufficient attention or respect to education and do not believe there is the same value in learning as do the people of other countries. As the author has pointed out, the British engineer has to compete now —and the competition will be keener in the future— with technical men trained in the United States and in European countries. There are more engineering colleges and more engineering students in America than in this country. As for the Continental engineer, he has a much more liberal education than the British engineer. To find a reason for the British attitude against higher university training it seems to me that we must go back some years. We were the first engineering nation when engineering in its infancy was purely empirical. The fact that we have inherited the empirical tradition leads us to believe that that method is still the best way to advance. Scientific research now begins to predominate, especially in electrical engineering, and while we led in the past we may not lead in the future, when the empirical method will be of less value than the scientific method. In America my experience was that a man had a better technical training, though his general education was no better than here. The American universities have no difficulty in placing students in manufacturing concerns. To have a B.Sc. degree is a handicap to a man here when he asks for a job from an old-fashioned employer. In America they take men who have gone through an engineering training and have an engineering degree and put them into any kind of industrial work. When visiting Dr. F. W. Taylor of "Scientific Management" fame in Philadelphia, the young man who showed me over the works told me he was studying the Taylor system in order to apply it to meat packing. Few here I think would associate meat packing and engineering. In this country the "captains of industry" are between 50 and 60 years of age, with a few exceptions of young men of ability who have inherited business position. Of the men between 25 and 35, the potential captains of industry 15 years hence, many have been killed in the war. On the other hand, in 15 years' time the younger generation, who missed the war, will have to fill up a gap which has never been experienced before, because not only have the men of intermediate age been killed but the demand in the engineering industry will be greater. Something will have to be done to fill that gap, and therefore I am chiefly concerned with those who will be the big men 15 years hence. What education should they get to maintain the prestige of the profession in competition with the engineers of other countries? It is from that special point of view therefore that I propose the following scheme of education for such men as have the character and ability and the necessary time to train themselves for such big positions. Such a man should take his Arts degree. For an ordinary M.A. degree in Scotland a student will start about 16. He should therefore take his M.A. at 19, which will give him a training in mathematics with some knowledge of economics and science, so that when he continues his studies during the next three years and takes his B.Sc. degree he will be able to give more of his time to technical engineering subjects instead of to mathematics. In the past, Scotchmen were too poor to go to the university

for more than 6 months in the year, which explains the short 6 months' session of the Scottish universities. As Glasgow University was the first to teach engineering science, the short session and the large engineering community naturally evolved the sandwich system which gives the student 6 months at the university and 6 months in the workshop. Premiums for apprentices have been practically non-existent in Scotland for some years. In America they are not tolerated and there the student apprentice can earn a living wage. The continuance of the premium system in England is an anachronism and will have to go if we are aiming at efficiency. The student ought to be able to support himself for at least half the year. In this direction the engineering employer must co-operate with the university and thus decrease the strain on the parent, to the benefit of the whole profession as well as the individual. By the time he is 22 the student can have two degrees and have had 3 years' practical training. Instead of trying to load up the engineering science course with short courses on commercial subjects he could study economics, psychology, and sociology in his Arts course, and in his Science course concentrate entirely on the applied science of engineering. After this let him have a year of commerical training in accounting, business methods and organization, finance, statistics, and perhaps " scientific management." By that time his mind will have been formed, he will have had 3 years' practical experience and will be better able to grasp those wider and more general subjects which are not likely to interest him at all as a young student. This training therefore covers 7 years—the time it takes an advocate to train for the Scottish Bar, this long training being one of the elements that build up the prestige of the barristers' profession. During his university career the engineering student should not concentrate so entirely on lecture and laboratory courses as to neglect athletic sports and especially public debate. It is unnecessary to dwell on the function of sport in training the young engineer to co-operate with and handle other men. As for public debate, all practical men profess to scorn and despise it and imagine it is a gift that is very easily acquired and is seldom based on any first-hand knowledge. We have just been humiliated by lamentable examples of the inability of the employer witnesses at the Coal Commission to state their case strongly and intelligently and to stick to it in spite of the irrelevant badgering of labour representatives and socialist " intellectuals." Engineers can hold their own with any in the production of papers on engineering subjects. The ability to speak in public on something that has not been written, and the ability to withstand cross-examination by opponents determined to get the better of one, opponents whose tactics will always be clever and often irrelevant but who will tolerate no irrelevancy on the engineer's part, is a very different matter. Until our " captains of industry " can face this ordeal and come out of it with credit, their prestige will never be what it ought to be, measured on the basis of their service to humanity. If the present " captains " cannot do it and think it not worth while, the future " captains " must or the barristers and labour agitators will carry everything before them. Public speaking is not easy. It demands a lot of training and practice and the engineering student should be encouraged in every possible way to take full part in the different debates at a university, not on engineering subjects in which the student is embarrassed lest he display technical ignorance, but on general subjects in which it is a battle of opinions as well as facts. Engineers must cease to scorn such wordy warfare, simply because they won't take the time to train themselves and seem to prefer ignominious defeat. After completing his 7 years' training, the young engineer should leave this country for two or three years at least and visit both Europe and America. After this further 7 years' experience at home and abroad the engineer will be 30 years of age and I guarantee he will be worth £2,000 a year when he starts at that age in a position of real responsibility. I am sure that in 10 to 15 years our present student would have no difficulty in getting that money. It is easy to get men now worth £500 a year, but the higher one goes the more difficult it gets, simply because their technical knowledge and practical experience have no higher economic value. I was much interested in the Appendix diagrams. If one looks at these diagrams one will find that the horizontal scale gives the individual remuneration, but the vertical scale of individual capacity is shown the same in each case. By means of circular diagrams it is possible to show relative money values and qualifications from the manager downwards.

**Mr. J. H. Buchanan** : I think the general conclusion arrived at in this paper, that the young engineer should receive some definite course of instruction in commercial and administrative subjects, is one which few persons will question. The chief difficulty in regard to the practical application of this conclusion lies in the already over-burdened state of the usual college curriculum, and the consequent objection to the inclusion of additional subjects. We must look at the matter to some extent from the point of view of the average student. In my own experience I have found that many students fail to do as well as they ought in certain classes, from sheer inability to assimilate knowledge at a rate exceeding their own critical speed. In such a case the student commonly lets one subject slide—it may be the very subject he is weakest in and to which he ought to give particular attention. The student then finds himself able to put up a satisfactory performance in his other classes, but he may have to spend an additional year at college, or in some cases he may even leave without taking his degree or diploma. Under the circumstances I consider that there are serious objections to the inclusion of the new subjects in the college course unless the duration of the latter is extended. The author proposes to surmount the difficulty by curtailing the teaching of design. Against that suggestion I protest most emphatically, and I believe that he takes too narrow a view of the benefits to be derived from instruction in this subject. I am strongly of opinion that every student should attend design classes, not at all with a view to being able to earn his living as a designer, but because in no other way can he become so intimately acquainted with funda-

mental principles and, I will even assert, with many of the practical and commercial aspects of the construction and properties of various kinds of plant. Knowledge imparted in the design class, besides filling up gaps in the courses of lectures, is essentially quantitative and is therefore a fitting complement to the knowledge, largely qualitative, which is imparted in those other classes. The engineer cannot make full use of his technical knowledge unless he can reduce it to figures whenever the need arises. Ability to do this, and an almost fatherly understanding of the inner nature of his own particular kind of machinery or structure, are the things which the student learns in a peculiar degree in the design class. The question therefore arises: "When is the necessary instruction in commercial subjects to be given?" I suggest that it might be arranged during the term of apprenticeship or pupilage, when, for a month or two, one forenoon or afternoon per week could be allotted for this purpose. I see no serious reason why the management of the firm should object, and I believe that the weekly hour or two spent amongst different surroundings and in a different mental atmosphere would be positively welcomed by the student. I am confident that under these conditions most students would appreciate the subject much more highly than at any period of the ordinary college course. I am glad that the author has emphasized the importance to the engineer of a good command of the English language. I have often remarked with regret the considerable percentage of students who are more or less deficient in this respect, though otherwise of good ability. These men are certain to be handicapped in some stage of their careers by the difficulty they find in putting their ideas into words. I think there is need for improvement in this department of the education of the engineer, and that some exercise in English composition would often be no less valuable to the student than the commercial training to which it might well be accessory.

**Mr. J. D. Taylor**: It seems to me that the time has arrived when engineers interested in the development of the young engineer must meet professors of engineering and face the problem together at the same table. The matter is of great importance to the nation. The practical engineer can say what the ideal engineer is from his point of view, but he has to depend largely on the professor to produce that ideal. I consider that we as a Centre should take an active part in the matter, and assist those interested in developing the education of the engineer by suggesting to the President and executive of the Institution the need for prompt action in the direction indicated. If some of our best electrical engineers and some university professors could be got together, I believe a solution of the problem would be found, despite the differences apparent in this discussion. The author suggested that facilities should be made available to the poor as well as the rich. I agree. The education of the nation as a whole is *the* question, and I think that when considering what facilities should be provided we should carefully bear in mind that young men without private means frequently deserve the fullest opportunities in the matter of education. The nation requires the brains of everyone; and education should be designed to fit each man to give the nation his best.

**Mr. A. Page**: There is a suggestion running through the paper which gives the impression that engineers as a class have failed to fulfil their destiny in the past, that opportunities have been allowed to slip, and that the present generation of engineers is not properly fitted to take its place in the scheme of things. I do not altogether agree with this view. We have numerous examples of engineers who are managers of engineering and railway works. There is hardly a supply company which has not an engineer at the helm. However, I agree heartily with the suggestion that business and commercial training should, if possible, form part of the curriculum at the technical colleges. There might be something done in that line at the schools. The new Education Act which, I understand, assures that in the great majority of cases boys will be in touch with school till they are 18 years of age may provide the desired channel. It appears to me that the whole problem is indissolubly mixed up with the question of how long a boy should be allowed to remain at school and at what age it is considered necessary he should leave to earn his living. One thing we must try to avoid is that there should be no slurring over of the student's technical education. We must not forget that the qualifications which go to make success in management are not a monopoly of the engineering profession; and no matter what training a prospective manager may have had in the earlier stages of his career, this will often be counterbalanced by want of sound judgment, self-reliance, and imagination. Common sense must also be taken into account. At present there is too much dissension in the engineering ranks and too many opportunities given to politicians and others to divide and rule. What we engineers require is to have greater interchange of ideas and comparison of methods Should these matters be properly dealt with, the engineer is more likely to take a higher place in the business world. I wish to endorse all that the author has said about general education. That part of the paper to my mind is more full of meaning than other points which have been debated at length.

**Mr. D. S. Munro**: It is certain that some knowledge of accountancy is necessary to the engineer, for financial efficiency is an essential purpose in any proposed undertaking. Again in the course of work the book-keeping element constantly recurs. Probably most engineers would approve of the author's scheme for a short and varied introduction to commercial methods and economic laws. Personally I would not favour a longer course except for those whose abilities or ambitions impel them to continue such studies when their formal engineering training is completed. Diversity of gift is of value to the profession, and it is desirable that the student should have the most significant gateways of knowledge at least pointed out to him. The difficulty is, perhaps, to find a subject which will be of no value to the engineer. Some of us, while jealous for the status of the engineer, have not been greatly concerned to see the most remunerative prizes fall to those who are strongest on the commercial and financial side. We recognize that there should be some com-

pensating element for those who are, to some extent, cut off from the full field of creative engineering. I note in the diagram in the Appendix that the financial faculty reaches zero in the ideal foreman. The author wisely stops short without attempting to express (even as a negative quantity) the financial element in the modern workman. In conclusion, I consider that a short course on the lines suggested would be welcomed by many engineers who have long completed their scholastic apprenticeship.

Lieut.-Colonel W. A. J. O'Meara (*in reply*) : The author fully recognizes that it may be difficult to work subjects additional to those taught at present into the college curriculum, but he finds it impossible to persuade himself that the difficulty is an insuperable one. He feels, now that courses for a degree in commerce are proposed widely—and have been and are being established in some centres—with a little compromise something could be done to enable engineering students to participate in instruction in administrative and commercial subjects, in cases where such is provided, somewhat on the lines proposed by Professor Hudson Beare. Once a beginning is made the importance of the instruction proposed by him will, the author is convinced, be quickly appreciated; under such circumstances, the responsible authorities may be forced to take action hastily which ought to be taken deliberately and with due consideration. It seems therefore to be most undesirable to postpone reforms in the engineering curriculum until such time as the courses are extended to a period of four years, in spite of the fact that a case for the extension of the engineering courses has been clearly made out. The author was fortunate in his young days, for although his technical education began in the early days of 1880, even so, it extended over a period of four years. In those days there was less to learn in engineering science than is the case at the present day, but the instruction which the author received was not confined to purely engineering subjects and he had the good fortune to acquire a knowledge, during the four years in question, of some of the subjects instruction in which he suggests should be given to the present-day engineering student—book-keeping he learnt at school before competing for Woolwich. It was because the author realized the great advantage that he has derived during his engineering career from the knowledge of administrative and commercial matters—a knowledge which he has in recent years found is not generally possessed by young engineers of to-day—small as it was, that he was emboldened to accept the President's invitation to prepare and read a paper in connection with the education of the engineer.

The author has called attention in the replies already published in connection with the discussions on his paper in London and at Cardiff (pages 239 and 315) to the misconceptions which appear to have arisen as to the nature and scope of the instruction in administrative subjects proposed by him and it is therefore unnecessary for him to enlarge upon the matter here. For a similar reason, it is proposed to pass over the subject of "co-operative courses."

The university education for the engineering student proposed by Captain Scott-Maxwell is one which is undoubtedly calculated to provide the engineering profession with very high-grade men. The author is entirely in favour of the scheme, but, unfortunately, few parents have purses long enough to admit of their giving their sons so thorough an education as that suggested. Something of the kind is, the author is aware, in force at Harvard, but the adoption of such a scheme in this country would, it seems, lead to a very considerable decrease in the number of engineering students. The author has been frequently consulted by parents who desire their offspring to adopt engineering as a profession; the chief anxiety of the parents appears to be to start their sons on an engineering course at as early an age as possible in order that the lads may be in a position to begin earning their own livelihood as quickly as possible. The author, in discussing the situation with parents, finds that few of them can afford (pecuniarily) to act on advice which takes the far-sighted view of a lad's future career. No doubt something might be done to improve the present situation were engineering employers to co-operate to a greater extent than they do at present with the universities in the matter of the engineering student's technical training. On the other hand, the author feels that it would be wasteful for every engineering employer to attempt to provide instruction in commercial subjects for his students. If the burden of this instruction must be borne directly by employers, as suggested by Mr. Buchanan, the most advantageous course for them to adopt would be to co-operate and start systematic courses in administrative and commercial subjects at important centres where large numbers of students (say 50 to 60) can be collected together.

Captain Scott-Maxwell's further suggestion that engineering students should be encouraged to take full part in college debates on general subjects is of very considerable importance and deserving of immediate attention. Teachers of technical subjects in our universities would be performing a great public service if they kept this matter constantly before their students and continually impressed its importance upon the latter's minds.

The author by no means accepts the view that his proposal to curtail slightly the teaching of design with a view to providing time for instruction in administrative and commercial subjects can rightly be considered to indicate that he takes too narrow a view of the benefits to be derived from the teaching of design: it would be as logical to argue that because a contractor with limited capital supplied his excavators with shovels in reduced numbers in order that he might supply them with a few pick-axes as well, therefore the said contractor thereby gave proof that he underrated the value of a shovel as a shifter of spoil. In the practical everyday affairs of life "good" is always battling against "best," and practical men adopt that which is "good" rather than bring machinery to a standstill by waiting for that which is admittedly "best," but which, for some excellent reason or another, may be impossible of attainment at the moment. Were it not for this "give and take" attitude in mundane affairs material progress would be enormously slowed down in this universe. It is submitted that similar considerations apply in the educational world.

The author has nowhere argued that all British engineers have failed to fulfil their destiny, but he would point out that, within the past 25 years, he has met instances in two of our colonies of preference being given to engineers educated in foreign lands—in one colony the engineers engaged by an important corporation were Americans, whilst in another they were Germans. The author further thinks it must be patent to everyone that in this country the engineering profession, as a corporate body, has not in public life that weight, nor indeed that status, which really belongs to it by virtue of the benefits conferred on the community at large by the activities and toil of its members. This may be due to some extent, as Mr. Page suggests, to the fact that at present there is too much dissension in the engineering ranks. The author's personal experience, however, has convinced him that engineers have in the past allowed themselves to be exploited mainly because they have not possessed that elementary commercial knowledge which would have enabled them to shake off the fetters of those occupying administrative positions; officials in such positions, human nature being what it is, have naturally designedly pursued a course calculated to keep the engineer in subjection to themselves. The situation is one which happily can be remedied and the author feels that the day cannot now be far distant when the little voids in the scheme of education provided for the engineering student will be filled up. When this has been done the engineering profession will acquire added strength and vigour: then indeed will the whole body of British engineers be in a position to fulfil completely their destiny, and the author has no doubt whatever as to the final triumph of his old profession over the ancient prejudices which have been responsible for the failure on the part of the management of many important technical enterprises to assign to the engineer that sphere of activity where his experience and knowledge can be most fully and advantageously utilized.

# DISCUSSION ON

## "THE SUPPLY OF SINGLE-PHASE POWER FROM THREE-PHASE SYSTEMS."*

NORTH-EASTERN CENTRE, AT NEWCASTLE, 10 FEBRUARY, 1919.

**Mr. J. Rosen**: The author has based his paper on the assumption that single-phase power is the most suitable for furnace use; three-phase furnaces are being installed throughout the country and I believe compare more than favourably with single-phase both in design and in operation. As a designer of electrical machinery, I should like to say that in view of the auxiliary apparatus necessary with single-phase supply to the furnace the three-phase system appeals to me, more especially with a power factor of 0·85 to 0·90 which is obtained; on making due allowance for possible out-of-balance effects, a standard frame for 0·80 power factor might readily be adopted for the generator. Even with furnaces close to the power station, where the author suggests separate single-phase generators might be adopted, three-phase supply is preferable, as it is not possible to design single-phase generators with such high efficiency as a three-phase generator or for such high speeds. The initial outlay in generating plant would therefore be greater with the single-phase generator, and the steam consumption would be higher. Should it, however, be found desirable to install the single-phase furnace it would be found of advantage to connect it through transformers direct to the three-phase supply, which would result in a better load factor. I should like to congratulate the author on the means he employs in overcoming the difficulties in the design of the balancer. It appears from the outline sketch that if a fault occurs on the single-phase windings it would be necessary to dismantle the entire high-tension three-phase stator winding. With the combined single-phase and three-phase windings in a single stator, considerable distortion of flux must occur on load and the eddy-current losses in the iron and copper will be more that 66 per cent of the no-load iron losses. I would estimate that these losses would be at least doubled; but perhaps the author has been able to obtain more information on these points. With these high losses it is probable that hot pockets occur which will be a source of trouble and possible failure. I notice the compensating winding comes in contact with the low-voltage winding and, as it is at the maximum potential of the high-tension winding, it is a source of weakness. If possible it would be better at the star. The author states that the current in the phases is balanced at all loads, but this is not confirmed by the no-load test; the reason given is the eccentricity of the tapping at the star. Is not this out-of-balance due to the compensating windings in the two phases? The effect of the flux across the leakage path is not proportional to the load and there will be a certain electromotive force still induced in the compensating coils at no load, which will cause a reduction in the current taken by the plases A and B. Apart from reliability, the great

* Paper by Prof. Miles Walker, D.Sc. (see pages 109 and 277).

drawback is the low efficiency, as the loss in the balancer is at least 10 per cent, which compares most unfavourably with static transformers. The balancer as a transformer for three-phase transmission could be used as a power-factor corrector—at the same time it could be designed more efficiently—and I think would have a wide sphere for this purpose. Great stress has been laid in the paper on the necessity for having the phases of the system accurately balanced. My firm supplied two 5,000-kw. sets to Australia 10 years ago and it was found after putting them into commission that the generators were 10 per cent shy on one phase. This out-of-balance in current was due to the unsymmetrical end windings on a split stator, and the effect was accentuated by the stator being very short, with the consequent high self-induction of the end windings. This difficulty could have been readily overcome, but the engineer found that no trouble was experienced with the out-of-balance. If no trouble is experienced with the out-of-balance constantly on one phase on all the plant on the system, I question whether the elaborate apparatus put forward is really necessary, as the out-of-balance can be kept at a comparatively low figure even if the single-phase furnaces are directly connected to a three-phase supply, as the furnaces would form only a portion of the load on the system.

**Mr. J. R. Beard:** While phase changers of various forms have been designed and used to a considerable extent in America, there has hitherto been no call for them in this country. We may therefore feel a legitimate pride in that a British engineer has designed the ingenious apparatus described in the latter part of the paper. At the same time it appears to me that the crux of the subject-matter of the paper is contained in the statement on page 110, that when unbalanced single-phase power is taken directly from an ordinary three-phase system "it is established that if the single-phase load (even of low power factor) does not exceed 20 per cent of the normal three-phase load the disturbance to the voltage is inconsiderable." It will also be found that most alternator builders will agree to, say, 15 per cent of the output of the machine being taken as unbalanced single-phase power without any departure from the standard construction. For some years past, the maximum demand on the power companies' system in this neighbourhood has exceeded 100,000 kw., so that 15 per cent would be 15,000 kw. As a matter of fact, large furnaces taking upwards of 1,000 kw. have already been operated single-phase without any special precautions and without any trouble arising. Additional ones are also in process of construction. Of course the system is balanced as far as possible by evenly distributing the various single-phase loads between the three phases. In view of the present tendency towards concentration and linking up all over the country, I feel, therefore, that the field for the author's apparatus will be extremely limited. Consumers requiring single-phase power will naturally turn towards the larger systems in order to avoid the additional capital and running costs of balancing apparatus. The main arguments for the balancer for furnace work are therefore its additional properties as a power-factor corrector and inductance. To enable an estimate to be made of the importance of these I would ask the author for information on the following points: (*a*) To what percentage extent can the maximum power absorbed by a furnace exceed the normal amount over a power-factor range from 0·95 to 0·7? (*b*) What are the additional capital cost and running charges (on, say, 50 per cent load factor and ½d. per unit) of supplying a furnace from an 11,000- or 20,000-volt network through the author's balancer, as compared with (1) a simple single-phase transformer, (2) a single-phase transformer with sufficient reactance to give 0·7 power factor on the furnace, plus separate phase advancers on suitable large motors in the neighbourhood to correct the low power factor of the furnace? In America a certain amount of railway electrification has been carried out single-phase, but with a phase changer carried on each locomotive so that polyphase motors can be used. Does the author recommend his apparatus for similar duty? I notice that many of the balancers referred to in the earlier portion of the paper give as much out-of-balance at no load as they correct for at full load. With the fluctuating loads of furnaces and single-phase traction this is a great advantage. Are the author's machine and the static condenser method free from this defect? I trust that the author will not rest content with his phase advancer and his phase balancer but that the Institution may yet have the pleasure of hearing him describe the ideal frequency converter. There is a really pressing need for some apparatus of this kind to replace the expensive and inefficient motor-generator frequency-changing sets.

**Mr. L. H. A. Carr:** I would point out that the term "balancer" as applied to the special machine described by the author in part (5) is the wrong term to use. The full title given by the author—"a rotating balancing transformer"—is correct since the machine does not simply balance in the ordinary sense of the word, but transforms, as the whole of the power goes through the machine. I was disappointed on studying the paper to find that the special machine described in part (5) was only suitable for working with a low internal power factor (such as 0·7) with the corresponding drooping voltage curve, for, since the compensating electromotive force which causes the three-phase side to remain balanced is dependent for its existence on a large leakage flux, it is impossible to design a machine to work on this principle where small leakage and good voltage regulation are essential, for example in traction work, and hence the machine is limited in its application. I would also point out that, though the power factor of 0·7 on the single-phase side is brought up to 1·0 on the three-phase side, it is not a case of getting something for nothing, but the necessary over-excitation has to be provided for this purpose just as in any other type of synchronous machine. I should be interested to know how the end windings of the machine are arranged so that the two windings do not foul. I should also like to know whether, on striking the arc and so practically short-circuiting the single-phase winding, there is a heavy transient current due to the eddy current in the field magnets opposing any change of flux, or whether the three-phase winding shields

the single-phase winding from any such effects. I should like to know why Fig. 26 shows a compensating winding in all three phases. Is it meant to be a general case? The shifting of the star point by means of tappings along one phase (Fig. 27) is bad, particularly in the machine described, for since the discarded turns are all cut out from one coil the armature reaction, and hence the flux, will have a different maximum in different parts of the machine, and with the single-phase windings in parallel this will, to a certain extent, unbalance the currents in the different single-phase coils. There will also be a slight want of balance in the three-phase winding due to the variation in permeance round the machine, owing to the single-phase slots not being punched behind all three phases. It has been my experience that any want of balance in turns, and any variation in permanence, are always accompanied by extra iron loss. I would ask for a clearer interpretation of the $D^2 L$ constant in Appendix VII. What are the units in which the constant is expressed, and which value of kilowatts has been employed? It is an unfair comparison with other machines if the output of the machine is taken merely as the output of one winding.

**Mr. H. W. Clothier:** In the schedule of methods obtaining single-phase power the author has omitted one of the existing methods. This is to take single-phase power directly across each of the respective phases of the three-phase system. I have in mind a large installation in the Midlands where there are a number of single-phase 150-kw. furnaces taken off a split-conductor feeder from a power station of approximately 12,000 k.v.a. active generating capacity. The furnaces are uniform in size and the switchgear is so arranged as to avoid an undue out-of-balance in the load. The consumer's high-tension system consists of a 6,000-volt three-phase ring main busbar into which single-phase double-pole switches are plugged for the supply to the furnace transformers. Each panel has plug receptacles for all three phases, but the switches are of the three kinds, there being an equal number to plug across each pair of phases. A distinctive colour-marking shows at a glance how many switches are fed from red and white, red and blue, and white and blue bars respectively, and by equalizing the numbers of the three kinds of switches in use a reasonable balance in the load is obtained.

**Mr. H. S. Ellis:** I have given this subject a great deal of attention during the past few months, my problem being to obtain a satisfactory supply of single-phase current from three-phase generators for general supply purposes, i.e. lighting, heating, power, etc., in which case it is of the utmost importance to ensure a perfectly steady voltage. At South Shields we had, until about four years ago, two distinct systems, namely, single-phase (50 periods) with transformer sub-stations where the busbar pressure of 2,100 volts was reduced to 220 and 110 volts, and a direct-current system at 550 volts which is used for traction and power. In addition to the reciprocating plant there was installed a turbo-generator (1,500 r.p.m.) consisting of a 1,500-kw. turbine, a 1,000-kw. d.c. generator, and a 1,000-kw. single-phase alternator in tandem. In 1914, owing to the increasing demands for current for power purposes, I considered the question of installing a second set such as I have just described, but after careful consideration I decided that the future requirements of the area called for a supply of three-phase current. Consequently a 2,000-kw. turbine (3,000 r.p.m.) coupled to two 1,500-kw. alternators (2,100 volts) in tandem was installed together with rotary converters. The advantages of such a set will be obvious when I state that the alternators were specially designed (by the author, I believe) to comply with my specification which called for each alternator to be capable of generating 1,500 kw. three-phase or 1,200 kw. single-phase. The set was therefore suitable for supplying three entirely separate systems, i.e. three-phase, single-phase, and (through the rotary converters) direct current. The 1,000-kw. alternator (1,000 r.p.m.) has recently been rewound and made exactly similar to the two alternators which I have just described, and the capacity of the turbine has been increased by 500 kw. by adding a new nozzle block and a new first diaphragm. All the alternators can be run in parallel either as three-phase or single-phase machines. It will be seen, therefore, that there are now three distinct sets of busbars in the station, consequently three distinct types of generators have to be kept going. I am aiming at having one system of generation only in the future, namely, three-phase; but as it will take some time to accomplish this I now propose to install Scott-connected transformers, so that I shall be able in future to do away with the single-phase generators and obtain all the single-phase current I require from the three-phase busbars. Then by installing more rotary converters I shall be able to do away with the direct-current generators and so, ultimately, I shall obtain the whole of my supply from three-phase plant. Obviously this will be a great advantage, insomuch that it will decrease the amount of standby plant and, furthermore, it will make it a comparatively simple matter to extend the plant in the future. Whereas with the present arrangements we should be extending three systems of generation and providing three sets of standby plant, we shall, if my scheme is adopted, extend only one system. It might be as well for me to explain that the arrangement I have suggested will call for the grouping of the single-phase feeders into two groups, a perfectly simple arrangement since the existing switchboard is split so that there are a number of feeder panels on each side of an interconnecting switch. By this means the load on the Scott-connected transformers will be fairly evenly balanced. The whole of the pressure regulation will be done on the three-phase bars, but should a higher pressure be required in any particular district, static boosters could be used on individual feeders. I have searched the author's paper for some other suitable method of meeting our case, but I cannot find one, therefore I should value very highly his opinion on my suggested scheme. I might say, in conclusion, that owing to the action of certain Government departments in holding us up in connection with our extensions, it now behoves us to make the best possible use of our present plant because, whereas the transformers I have referred to could probably be obtained in from 12 to

16 weeks, it would take as many months or more to obtain new generating plant.

**Mr. W. T. Maccall:** I had expected from the title that the paper would include a discussion of the methods by which static transformers can be connected so as to effect a partial balance when a single-phase load is supplied from a three-phase system. This would have added somewhat to the value of what I feel safe in describing as a classical paper. I should be grateful if the author would supply us with the approximate values of the power factors to be expected with single-phase loads other than furnaces, especially for welding, and so enable us to determine how much advantage is gained by the adoption of the various methods of connection mentioned above.

**Mr. J. W. Jackson:** One important point made by the author is that, generally speaking, the single-phase electric furnace has several important advantages over the three-phase furnace, in that the single-phase circuit is not so liable to short-circuits owing to the fact that the other electrode is at a considerable distance away, whereas in the three-phase furnace the two phases which are led in through the roof are compelled to be comparatively close together and, due to various causes, somewhat frequently short-circuit, melting the roof of the furnace and thereby putting a complete stop to production. Another important point is that the single-phase furnace can apparently be run on a much lower carbon cost per ton of output than is the case with the three-phase furnace. Again, it is found that the single-phase furnace can be supplied direct from a three-phase system without the intervention of auxiliary apparatus, provided that the three-phase system is of a large capacity or that the furnaces can be installed quite near to the power station so that the batteries of them can be made to balance one against the other. The best point, however, appears to be that by the installation of the single-phase rotating balancer it is possible to supply single-phase power to a furnace from a small three-phase system, or from the end of a long three-phase cable, and at the same time this balancer can be so arranged as to correct for the bad power factor produced by other induction motors in the vicinity, thereby reducing the wattless current on the mains or system to a minimum. This apparatus, therefore, has the advantage that in the event of a short-circuit developing the generator is practically wiped out; whereas on any of the above systems in the event of a short-circuit the effects to the furnace, cables, or the power station might be serious.

**Mr. A. H. Finch:** I should like to know whether a good enough balance cannot be obtained by static means. I understand from the paper that it is possible to neutralize the unbalancing effect of a given single-phase load by choke coils, but that when the load is varied or reduced to zero the choke coil or other device employed will introduce as much out-of-balance as it removed when the load was on. Is it not possible to regulate the choking device so as to give a sufficiently good all-round compromise? The paper indicates a counsel of perfection for one application, viz. the steel furnace, but is the method advocated equally applicable to other uses of single-phase current, e.g. traction, welding, or such single-phase supplies as still exist in parts of Newcastle and South Shields?

**Mr. A. Collins:** There is a point arising out of Appendix I to which I should like to refer and which also has some bearing on the author's previous work,* and that is the relative intensity of single-phase and three-phase short-circuits. Information is given as to the ratio of the field ampere-turns for steady short-circuit conditions. In determining the requisite breaking capacity of an oil switch, account has to be taken of the instantaneous short-circuit current, and more particularly the rate at which it decays to the steady value, as an oil switch does not open circuit until after the elapse of at least one-fifth of a second from the application of the short-circuit, and may be arranged to operate even later. It would appear that owing to the reduction in the armature strength the instantaneous value of a single-phase short-circuit would be less than that of a three-phase short-circuit, assuming other conditions to be similar in each case, while in the case of the steady values the single-phase short-circuit current will be greater than the three-phase current. Apart from these two points on each curve, the single-phase current will decay less rapidly than the three-phase current. In other words the single-phase transient will approximate nearer to a straight line than the three-phase transient, and it is conceivable that the value of the current at the point at which an oil switch operates will be greater for single-phase than for three-phase, so that the number of kilovolt-amperes to be handled by each individual phase of the switch will be greater in the case of the single-phase short-circuit, particularly where the fault occurs near to the generating plant and the impedance of the connections is relatively small. I should be glad to have the author's views on this, and to hear whether he can make any general statement as to the relative dimensions of the two short-circuit transients.

**Professor Miles Walker** (*in reply*): Mr. Rosen in his remarks as to his preference for a three-phase supply leaves out of account altogether the characteristics which are so desirable in the electric furnace circuit. Small differences in efficiency or cost of power are of no account compared with the advantage of stability in the furnace circuit. If one has to introduce this stabilizing influence and then correct the power factor, it is just as easy to convert at the same time from three-phase to single-phase.

The answer to Mr. Beard's questions are as follows: (*a*) Where the balancing transformer is used it is impossible for the furnace to take more than the normal input. The maximum input occurs with an internal power factor of 0·7; at all other power factors the input is less than the normal. (*b*) The cheapest proposition from the point of view of capital cost is of course the simple single-phase transformer without reactance, but for the reasons given in the paper it is not to be recommended even if the cost of the electrical plant were zero. The three alternatives that I will consider are (1) transformers with reactance working at 0·7 power factor; (2) the same with synchronous

* M. Walker: Short-Circuiting of Large Electric Generators and the Resulting Forces on Armature Windings, *Journal I.E.E.*, 1910 vol. 45, p. 295.

motors added to correct the power factor to unity, and (3) a synchronous balancing transformer running at unity power factor. Taking the capital cost of furnace, transforming plant and switchgear to melt 50 tons of steel per week we have the following figures: (1) £5,850, (2) £7,100, and (3) £7,500. The price of the electricity would in general depend upon the maximum demand and the power factor. In case (1) we should have a maximum demand of 750 k.v.a. at a power factor of 0·7, and a consumption of about 35,000 units per week. In case (2) the maximum demand might by means of some automatic device be kept down to 550 k.v.a., but no such device is at present on the market and the cost of it has not been included in the above figures; without such device the power factor would vary over a wide range as the furnace was put off and on. The consumption of units would be about 37,000 per week. In case (3) the maximum demand would be 550 k.v.a. at unity power factor, and the consumption about 37,000 units per week.

The objection raised by Mr. Carr to the tappings in the winding is not a very serious one. The tappings provide at most for a variation of 2 per cent in the voltage. The effect upon the armature reaction is entirely negligible. The effect of the difference in the permeance of the iron paths is also negligible, as can be seen by referring to the calculation sheet. In taking the $D^2 L$ constant the k.v.a. of the machine is taken as 444 k.v.a. Of course if we regard the machine as a motor-generator, there being two machines in one, the constant would come out about half the value given.

I think that Mr. Ellis's arrangement of plant to meet his special conditions is admirable and cannot well be improved upon. The division of the single-phase load into two independent parts each fed from Scott-connected transformers is quite good practice.

In reply to Mr. Maccall there is no way of connecting transformers which will make any improvement in the balance of the power unless some apparatus such as a choke coil or condenser is introduced. The reason for this is given in the paper and in my reply to Mr. Partridge (page 147). The power factor of a welding load differs very widely according to the plant employed; in most cases it is quite good and of the order of 0·8 and higher. As welding loads are not very great, there seems to be no difficulty in connecting a number of welding sets to different phases of a three-phase system.

Some of Mr. Finch's questions have already been answered in my reply to Mr. Maccall. It is not likely that the rotating balancing transformer will be used for single-phase traction because the amount of power required on traction is usually so great that it is worth while to provide special generators.

In reply to Mr. Collins I should say that it is very seldom that a symmetrical three-phase short-circuit occurs. The current in two of the legs always rises so much higher than in the other that the conditions approximate to a single-phase short-circuit though, as Mr. Collins says, the rate of falling off will be greater in the three-phase case, so that the switch will have an easier task.

# DISCUSSION ON

## "THE DETERMINATION OF THE EFFICIENCY OF THE TURBO-ALTERNATOR."*

North-Western Centre, at Manchester, 25 February, 1919.

**Dr. Miles Walker:** I quite agree with the authors that the method of determining the losses by measuring the temperature rise of a known flow of air is a sound one. The main difficulty seems to lie in the accurate measurement of the air. The method used by the authors is good, but it is open to the objection that we are not quite sure of the shape of the curve which gives the velocity at different parts of the duct. Especially near the edge of the duct the velocity curve is not known, and as the perimeter is considerable the error is not negligible. We cannot be quite sure whether the rectangle which gives the area of the curve should be 17 inches, 18 inches, or 16 inches wide. The difference between the square of 16 and the square of 18 is very considerable I have little doubt that improved methods will be used for measuring the air, and, even as it is, the method is much more satisfactory than other methods of determining these stray losses. In a number of experiments that we have been carrying out at the College of Technology we have found that

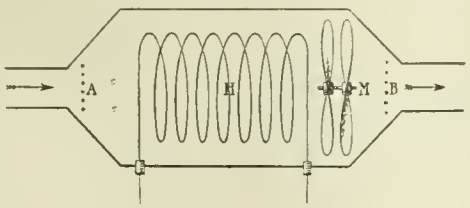



Fig. D.

A. Thermal junctions at entrance.
B. " " " exit.
H. Heater.
M. Fan blades rotating in opposite directions for mixing the air.

so reliable is the measurement of temperature in the measurement of losses that we have inverted the process for the purpose of measuring the air. The current of air to be measured is passed through a special calibrating box (Fig. D) which contains a heater consisting of a spiral of wire, the amount of power supplied to this being known. A number of thermal junctions of uniform resistance are connected in parallel and distributed over the entrance so as to take the mean temperature of the air coming in, and a number of similar junctions measure the mean temperature of the air going out. Knowing the watts lost in the spiral and the temperature rise, the flow of air is easily calculated. With a constant flow of air through various parts of our apparatus which represent various parts of the ventilating system of a turbo-generator, we know that the loss in any part is proportional to the rise of temperature in that part.† We can measure the temperature to 1/100th of a degree; and if we have 5 degrees rise in temperature in the air going through we get a very good measure of the flow of air. It will be quite possible in turbo-generators to have some such arrangement in the ducts feeding the air into the machine; and in that way we shall have, I believe, a very much more accurate measurement of the amount of air going into the machine than could be obtained with an anemometer. With regard to measurement of the temperature of the air going out, we have found that thermometers are rather troublesome. If one is dealing with a large area one has to use a number of thermometers in order to get anything like the mean temperature. A very much better method is to use a large number of thermo-couples of equal resistance connected in parallel. They are much cheaper than thermometers, and not so easily broken. With their aid it is possible to get the average temperature of the whole area at one reading, and the result is much more accurate than that obtained with an ordinary thermometer. This paper will certainly be of very great service in drawing the attention of engineers to the importance of measuring stray losses.

**Mr. J. S. Peck:** With the increase in size and speed of turbo-generators it becomes more and more difficult to measure the losses in the usual way, that is by means of a calibrated motor, and some method such as that described by the authors which will enable losses to be measured under running conditions on site, is likely to be generally adopted if it is found reliable. The methods described in the paper have previously been discussed on several occasions: they were dealt with in the paper by Professor Threlfall and in a paper read before the American Institute about five years ago. On this occasion the general subject of alternator efficiencies was discussed, and emphasis was laid upon the difficulty of measuring the volume of air. This seems to be the critical point of the whole scheme. About a year ago the Standardization Committee of the B.E.A.M.A. considered this general question of measuring alternator efficiencies, and various manufacturers were asked to submit their opinions upon it. Among others Messrs. Brown, Boveri pointed out that they had been using the air-measurement method for some time and obtained very satisfactory results. But they also stated that, as they were manufacturers of fans and compressors, they were quite accustomed to making exact measurements of air volumes, and therefore would probably not experience all the difficulties which were encountered by manufacturers unfamiliar with such measurements. Nearly all the other manufacturers recommended the "calibrated motor" method, and it was felt that until some method of measuring air velocities and air volumes had been perfected it

* Paper by S. F. Barclay, Ph.D., and S. P. Smith, D.Sc. (see page 293).
† H. D. Symons and M. Walker: "Heat Paths in Electrical Machinery," *Journal I.E.E.*, 1912, vol. 48, p. 674.

was better to adhere to the method of using calibrated motors. The final recommendation of this Committee was that the separate losses should be measured by means of a calibrated motor and that the total loss on short-circuit should be taken and not a compromise between the $I^2R$ loss and the total loss on short-circuit. The most important feature in the paper seems to me to be the design which the authors have worked out for securing a uniform rate of flow of air in the exhaust. The closeness with which the results obtained by different methods agree is really remarkable; it is better than one would expect from commercial measurements, but until further tests have been made I should hesitate to recommend the immediate adoption of the air-heating methods for determining efficiencies. If, however, further tests show that accurate results can to 100 lb. per square inch. The whole arrangement shuts up into a box 22 in. × 11 in. × 4 in. and is an extremely portable, accurate, and rapid instrument. To the left is shown a less portable differential gauge reading by a pointer on a dial having a double scale of from 5 to 70 feet per second air velocity and 0 to 1 inch differential water column by which differences of pressures of 1/1,000th of an inch (water gauge) can be measured. I gather that the authors favour the electrical method of Morris because it measures the air velocity independently of its direction. I think this is wrong, as the air may be travelling in any direction, possibly inwards at some points, and what is wanted is to measure the outward component of the air velocity only; such a measurement is given by a facing gauge kept normal

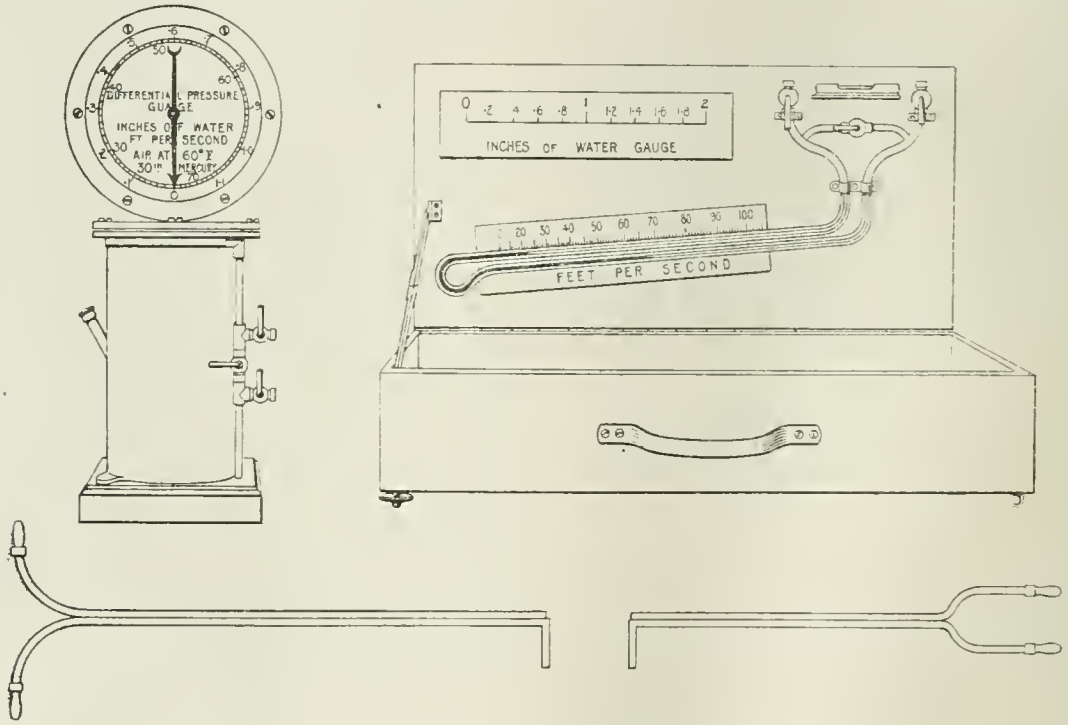



Fig. E.

be obtained by their use I think there is no doubt that they will be generally adopted for measuring the efficiencies of large turbo-alternators. If this comes about we shall owe a great debt of gratitude to the authors.

**Mr. J. Frith**: I have brought for the inspection of members some pieces of apparatus which Dr. Cramp and I have developed for the experimental and commercial measurement of air quantities. These are shown in the illustration (Fig. E) herewith. On the right is a portable micro-manometer reading directly in air velocities from 5 to 100 feet per second. For ordinary pressures the two ends of this inclined gauge are connected by rubber tubes to one of the forms of combined facing and side gauges shown in the foreground. The gauge is also suitable for pressures up to the opening. There is another electrical method developed by Thomas in America in which a measured amount of energy is used to heat the air, the temperature before and after being measured by a platinum thermometer in the form of a wire grid stretched across the air duct. Then the energy lost in the alternator is to the measured energy as the temperature rise in the alternator is to the temperature difference before and after the heater. This method is independent of the quantity or specific heat of the air used. I suggest that the platinum-grid thermometer would be more accurate than Dr. Walker's thermo-couples in parallel, in which arrangement the hotter thermo-couples would send current into the cooler couples and alter their temperature.

**Mr. H. C. Lamb**: This paper is of special interest

to station engineers because everyone who puts in plant wishes to test it himself after it is installed. We are able to do that with almost everything except generators, for which up to the present we have had to take the figures furnished by the makers who test at their own works. Although not wishing to cast any doubt upon their results, we think that all tests should be made by independent parties. There have also been a few cases in which disputes have arisen because the performance of a set has not come up to the guarantee and the turbine builder has wished to put the blame on the builder of the alternator. The method described in the paper would settle such disputes very easily on site. A couple of months ago it occurred to me that the efficiency of a certain alternator might be checked in this way and a comparison made with the figures obtained by the builders. It was a 20,000 kw. alternator and it had been very fully tested before delivery. When the test by the air method was made the load was kept constant for several hours at 17,000 kw., 0·85 power factor, 6,600 volts. The air was measured by an anemometer similar to the one illustrated in the paper, and it had been specially put in order for the test by the Manchester Instrument Department. The discharge duct was divided by cast-iron webs into 16 compartments. The velocity was taken in each one of the 16 divisions, and the air volume worked out at 67,840 cubic feet per minute. The inlet air temperature was 68·20° F. and the outlet air temperature—which was taken by specially calibrated thermometers on the average of 24 readings—was 110·67° F., showing a temperature rise of 42·47 degrees. Taking the weight per cubic foot for 110° at 0·07 lb. it gave the energy carried away by the air as 855 kw. The loss through bearing friction was assumed to be 100 kw., making a total of 955 kw. I had no idea how to estimate the radiation loss, so it was neglected. Those two losses gave an efficiency of 94·7 per cent and the efficiency taken from the curve of the tests at the maker's works was 94·6. After reading the paper I measured the surface of the carcase, which was 210 sq. ft., and allowing 0·006 watt per square inch it gives 7½ kw. of loss by radiation. When that was allowed for it brought the efficiency to 94·65 per cent, against the 94·6 per cent obtained by the manufacturers—a remarkably close result. It did not occur to me at the time that this was a method which would be recommended by scientific people, but after hearing the paper and thinking over my own results I feel quite sure it will be very widely used. It removed from my mind any lurking suspicion regarding the figures given by manufacturers—at any rate by the particular manufacturer in question.

**Mr. J. A. Kuyser:** The two methods described by the authors for measuring the losses on turbo-alternators have been in use for some years, but no results of tests have been published up to the present. One reason for this is perhaps that the results have been rather uncertain, at least in the case of the air-heating method. For the turbo designer who is anxious to obtain the stray load losses as accurately as possible, the calibrated air method looks the most attractive; it is very simple and requires very few precautions. It is only necessary to use a sufficient number of thermometers to obtain the correct average temperature. As regards the air-heating method, the general opinion is that air-velocity readings are very unreliable; the results obtained by the authors, however, check remarkably closely with the calibrated method and, if these results can be duplicated, the air-heating method should be very useful for the power-station engineer to check the results obtained on the manufacturer's test floor. I have used the calibrated air method for several years to obtain a comparison between load losses and short-circuit losses. The following table gives some of the results :—

| | | | |
|---|---|---|---|
| Normal | k.v.a. .. .. | 20,000 | 19,000 | 18,000 |
| | r.p.m. .. .. | 1,800 | 1,800 | 1,800 |
| | volts .. .. | 13,200 | 2,700 | 12,000 |
| k.v.a. during load test .. | | 15,000 | 13,000 | 14,500 |
| Load loss using no-load test for calibration, kw. .. | | 145 | 91 | — |
| Load loss using short-circuit test for calibration, kw. .. | | 141 | 139 | 169 |
| Short-circuit loss measured by calibrated motor, kw. .. | | 150 | 139 | 152 |

In these tests the no-load and short-circuit losses were measured by means of a driving motor. The load test was made at zero power factor by means of an under-excited synchronous motor. The tests are ordinary factory tests and the results are therefore not very accurate. The figures give, however, an indication that the short-circuit stray loss appears nearly in full during load conditions. In connection with these tests I would draw attention to the method proposed on page 299 where the authors recommend two temperature runs to obtain the calibration, namely, one run without excitation and one run fully excited. The calibration loss consists in this case of the sum of core losses and rotor $I^2R$ loss, while the fan losses and windage losses are eliminated. I should like to ask the authors the reason for this. The fan and windage losses are known as accurately as the core loss and have the same effect on the air temperature, and to obtain the calibration a single test fully excited on no load, or a short-circuit test should be sufficient, more accurate, and less expensive.

**Mr. G. A. Juhlin :** I think we should not overlook the necessity of obtaining data as regards the individual losses when considering the method of measuring efficiencies of large turbo-alternators. It is of extreme value to the designer to be able to segregate the losses in a machine with as much accuracy as possible. Unless we increase our knowledge in this direction, progress in design will be slow. The "calibrated motor" method has very distinct advantages, as it is possible to obtain accurately the various losses, with the exception of the load losses. It is of course possible to obtain readings of the individual losses by what the authors term the "air heating" method, but when we consider that it is necessary to run the machine until perfectly steady temperatures are obtained for each reading, it is clear that the time required in making these tests will be very great. My experience has been that as soon as a set is ready for running it has to go into service, and I am afraid operating engineers will object to having

a set tied up for any length of time for the purpose of carrying out tests. For this reason I feel it would be a mistake to substitute the air heating method for the calibrated motor method. The air methods are very valuable for determining the total losses under load which would make it possible to determine the actual load loss if the no-load losses are known. With regard to the comparison between the total losses obtained by the "air heating" method and by measuring the separate losses, we carried out tests on a 5,000-kw. machine some time ago and obtained good results. A chimney with two layers of wire gauze was used, and the resistance drop was not found to be excessive. I believe Professor Threlfall used very open muslin in his tests with satisfactory results. The total losses as obtained by the "air heating" method were about 8 per cent higher than the summation of the separate losses, taking the total short-circuit loss as equivalent to the load loss. The air speed was very uniform over the whole outlet of the chimney. In connection with the statement on page 294, that the heating of the lamination has been found to be less on full load than on short-circuit, it would be interesting to hear from the authors whether this is a usual occurrence or if it is an isolated case. It is difficult to accept this as a general experience and one would hesitate to draw the conclusion that the stray losses on load and on short-circuit are materially different. With reference to measurements of air volumes, the Thomas meter to which reference has been made is claimed to be very accurate. The principle underlying this meter has been applied for checking the air volumes in turbo-alternators. It is part of the routine testing to run the machine on field charge by means of a calibrated motor and measure the temperature rise of the air. As the energy heating the air and the temperature rise are known, the volume is easily and accurately obtained.

**Mr. R. E. Grime:** I agree with Mr. Frith in his criticism of Professor MacGregor-Morris's electrical method of measuring the air velocity, as applied to the present problem. It is desired to measure the average air velocity at the chimney outlet, normal to the plane of the outlet. If the air at any point is not moving normally to this plane there must be a side component, and the absolute velocity is then necessarily greater than the normal component. Professor MacGregor-Morris's ingenious instrument measures the absolute velocity at each point explored, irrespective of direction, and therefore gives too high a reading unless the air is everywhere moving in stream lines normal to the plane of the outlet. On page 298 wet air-filters are mentioned. If the proposed tests are carried out on a machine provided with this type of filter, it will be important to ensure that no free suspended moisture remains in the air entering the machine. The authors show that variations in humidity do not appreciably affect the results, but if any free moisture gets past the thermometer at the intake and is evaporated in passing through the machine, serious errors may result. The present paper puts the art of measurement of stray losses in turbo-alternators in a position very much ahead of that of their calculation. In view of the magnitude of these losses combined with their extreme undesirability, a wide field for further investigation is thus opened up.

**Dr. W. Cramp:** It seems to me that the unknown quantities in connection with the methods which the authors have put forward are two. The first of these is the amount of heat which goes into the machine itself owing to the specific heat of the material of which it is made. In particular with the calibrated air temperature method it seems certain that the machine cannot have reached its final temperature at the time the loss is measured; and nothing is said about the amount of heat which goes into the machine during the calibration period. Similarly with the first method it will not be possible to measure the efficiency of the machine unless it has first reached a final temperature. It would seem to follow that the measurement must be taken at the end of a long run, and that a correspondingly long run must always intervene between the time the test is taken on one load and the time the test is taken on another load, which makes the whole method rather slow. The other unmeasured quantity is the loss due to radiation, conduction and convection from the exterior of the machine. It seems to me that the the rule given in Appendix I for ascertaining this loss is too rough to be of any service. The authors suggest that the external surface should be measured and multiplied by a constant to give the total number of watts lost. Anyone who has tried to estimate the temperature of an ordinary direct-current machine knows how difficult it is to arrive at the value of the external surface. What is the external surface to include? Take the case of a turbo-alternator. Are the feet to be taken as part of the external surface? Are the bearings? It is surely not reasonable to take every square inch of the external surface and multiply it by the same constant. Nor is it possible to adopt the same constant for all types of turbo-generators. For example, some machines are smaller in diameter and of greater length than machines built by other makers, and it would not be reasonable to take the same specific loss in both cases. Speed and frequency also will affect the question. To get this allowance accurately we need a method better than that put forward on page 304 where 0·006 watt per square inch of surface per degree rise is mentioned. In connection with that I should like to call the authors' attention to some figures which are given in the current number of *Science Abstracts*, showing the loss of heat from plain iron pipes when steam passes through them at different temperatures. The variation of the loss with temperature is very considerable. Thus even where the surface is settled, it would not be satisfactory to take a single figure for all temperatures. I am very surprised that the authors refer to the anemometer as a satisfactory instrument, as I have found it entirely unreliable. To measure velocity with an anemometer we have to take not only the anemometer reading but also a reading of the time, so that we have a possibility of two errors. The authors propose to take a number of readings over a large area divided into a number of sections. It seems to me that that process will be very slow and possibly very inaccurate. For instance, in the diagram shown there are 81 squares and it is

proposed to take anemometer and thermometer readings in every one of those sections. The authors have commented upon the time that is taken in getting readings with the Brabée tube and micro-manometer, but surely that is nothing compared with what they recommend in connection with the anemometer. They say that the reading in each section should occupy at least 15 seconds, and as there are 81 sections they will require for a single reading at least 20 minutes. During those 20 minutes a number of things may happen. It is very difficult indeed on the ordinary test to keep the load absolutely steady for 20 minutes and the temperature in various sections may change. The method therefore leads to inaccuracies from the time taken to get a single reading. It is said on page 296 in connection with the anemometer that the frictional effect is not more than 3 per cent of the vane-wheel speed. I should like to know how that test was made, as it is an exceedingly difficult one. A little later there is a reference to the use of the Pitot tube to obtain the average velocity across the discharge opening. The authors say, "The mean air velocity was measured by traversing the Pitot tube across the discharge opening." Such an arrangement as that cannot possibly give by means of a Pitot tube the average velocity. With a suitable manometer it might conceivably give the mean square of the velocities in a rectangular pipe; but even that is unlikely and in any case would be very different from the mean velocity. If the anemometers were checked by this method the calibration would be of little use. Reference has been made to the question of the accuracy of the static gauge compared with the dynamic gauge. The static gauge is more likely to give trouble than the dynamic, but there does not seem to be any particular reason why the static tube should not be in the side of the duct square with the duct and flush with it. An advantage of the type of gauge illustrated by Mr. Frith's exhibit is that the static tube is quite close to the point at which dynamic pressure is measured. Now it is known that with a circular tube the pressure along a radius is practically constant. On the other hand it is known that the velocity across any section of the tube varies, being higher in the middle and going down almost to zero at the boundary. As the pressure does not vary with the radius of the tube the static tube may be put wherever convenient, and a safe place is at the boundary of the duct. A small hole quite flush with the boundary will give the best results, because the velocity along the boundary is low and probably below the critical velocity. I would also remind the authors that the shape of the velocity curve is well known in connection with round pipes. It has been shown by very careful experiments that, not only is the ratio of the mean to the maximum velocity almost constant, but also the position in the tube at which that mean velocity occurs is very nearly constant; that is to say, the radius of mean velocity is very nearly independent of the velocity and of the diameter of the tube. Therefore for accurate measurement it is desirable to use a round pipe for the air to pass through and not a rectangular pipe such as the authors used. There would be no difficulty I think in extending the tube slightly and making it round. I notice that although the losses are given in some detail, the sizes of the machines to which these losses refer are not mentioned. I hope that the authors will give these in their reply, and that they will include also the dimensions of the tube shown in Fig. 2. Among instruments for measuring the velocity of fluids, the authors do not mention the pneumometer,* which has been developed and used with considerable success in Germany. The action of the instrument depends upon the condition existing on the two sides of a disc placed at right angles to the direction of the stream the velocity of which is to be measured. On that side of such a disc which faces the current and close to the centre of the disc, the pressure of the fluid is given by the formula $p = v^2 \rho / 2 g$, where $\rho$ is the density of the fluid. On the opposite side of the disc it has been found by careful experiments that the pressure is lower than the above in the ratio of 1 to 0·37. Fig. F shows two forms of the

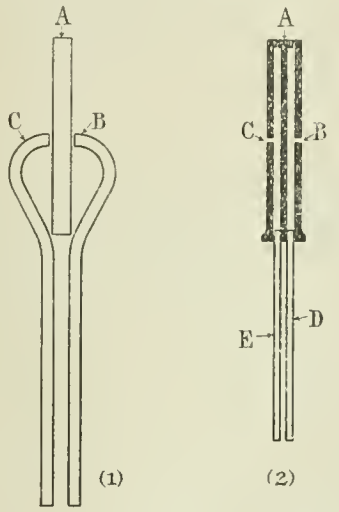



FIG. F.

pneumometer. In Fig. F (1) the disc A is placed at right angles to the stream and the two small tubes B and C, which very nearly touch the centre of the disc, are connected to the two ends of a differential manometer. In Fig. F (2) the two small tubes are replaced by the small holes B and C in the centre of the discs which enclose the main disc A, forming chambers which are in communication with the manometer tubes D and E. This second form is perhaps better than the other. In either case when the two tubes of the pneumometer are connected to the two ends of a manometer the pressure which the latter reads is $p = 1{\cdot}37\, v^2 \rho / 2 g \rho_1$, where $\rho_1$ is the density of the manometer fluid, from which the velocity of the fluid can easily be determined. The great advantage of the instrument is that inaccuracies due to variations in the static head are entirely eliminated, and that the velocity is measured practically independently of any other condition.

**Mr. F. J. Teago** (*communicated*): This paper de-

* *Proceedings of the Manchester Literary and Philosophical Society*, 1914, vol. 58, part 2.

scribing a method of calculating the losses in turbo-alternators is of great interest to me especially as I was concerned with similar experiments, using thermometers and anemometers, some 8 years ago. Retardation tests were also being used at the time and the object of the tests was to determine the magnitude of the stray loss. The authors are to be congratulated for having put the advantages of air-heating methods so clearly before us, and for having taken the trouble to show fully the derivation of all formulæ used. Table 3 shows that, taking the air-heating method as correct, the calibrated air-heating method gives results about 3 per cent high and the American method gives results about 4·5 per cent low. Now, to say with any certainty that the air-heating method is more exact than either of the other two, one would have to be certain that the measurements involved were capable of being made with great accuracy. Since the authors had to baffle the discharge trunk to obtain satisfactory anemometer readings it would probably have paid to use a Pitot tube in a trunk baffled at both ends as described by me in a short account* of some experiments made in the Electrotechnical Laboratories at Liverpool University. Most people are convinced that the Pitot tube, when correctly proportioned and properly handled, is a very exact instrument and much superior to the anemometer. The main objection to the use of baffles is the increased resistance they offer to the flow of the air. Provided, however, that the amount of baffling employed was as small as was consistent with precision in the readings, a Pitot tube arranged in a suitable trunk would constitute an almost ideal piece of apparatus for accurate commercial testing. One thing the authors do not emphasize is the objection to the use of mercury thermometers on alternating-current machinery where reliable readings are desired. It would be of great value, since the constructional details of turbo-alternators vary so little and since forced ventilation is so widely used, if the authors could extend the range of their experiments and obtain a curve similar to that shown in Fig. 16 of my paper.

* *Journal I.E.E.*, 1914, vol. 52, p. 563.

(The authors' reply to the discussion will be found on page 488.)

## North-Eastern Centre, at Newcastle, 24 March, 1919.

Mr. J. Rosen: I am pleased that the authors pay particular attention to stray losses on load—at present there is usually some discussion between the alternator designer and the turbine builder as to the efficiency of the alternator. As is well known, when the efficiency is taken by the "summation of losses" method it is higher than the actual efficiency. A tolerance of 1 per cent is usually allowed on the guaranteed figures. I think it is preferable to give the actual efficiency including all load losses. This is, after all, the desired efficiency, as the steam consumptions are based on these figures. The stray losses are dependent on many factors. Machines designed some years ago for good regulation had comparatively low stray losses, and in some cases these perhaps would not exceed 10 per cent of the no-load iron loss, but under these conditions the exciting energy was greater with the corresponding increase in the size of the alternator. The authors state that the stray loss may become a limiting factor in the size of large turbo-alternators; with this I am in agreement, not necessarily owing to the magnitude of the loss, but that on load local heating occurs causing "hot spots." It is therefore most necessary not only to measure the magnitude, but also to locate the source of heating and take steps to minimize or eliminate the loss. This is a point I would emphasize. Several sources of loss will at once come to mind, and perhaps the most important are the eddy-current losses in conductors—more particularly the joints—in the pole face, rotor end caps, stator teeth, winding clamps, and studs. There may be a large loss in the casing and end shields, but although this should be kept as low as possible, the results are not serious from a reliability point of view, as the heating in these parts does not affect the insulation, the most vulnerable point of an alternator. The separation of the losses is of great assistance in the design. One case occurs to me of a 500-kw. single-phase alternator, the temperature rise being found to be higher than expected. On careful testing it was found that the windage loss was 31 kw. or 6¼ per cent of the output. By the fitting of suitable baffles this loss was almost entirely eliminated. The retardation method was used in this instance. This method is not referred to in the paper, but I think it should not be overlooked.

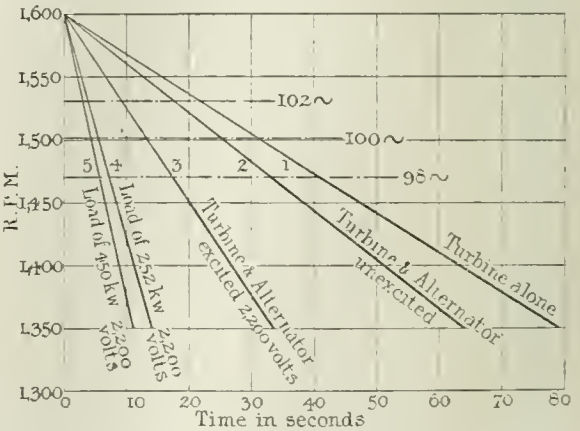



Fig. G.—Retardation curves for 2,500-kw. 1,500-r.p.m. 100 ~ single-phase turbo-alternator.

It is necessary to know the stored energy of the rotating parts, and this figure can be readily checked by repeating a test with a known load on the alternator either at normal voltage or, better still, at a fraction of the voltage only, when the stray losses under this condition are negligible. In the case mentioned before, it was not possible to measure the quantity of air passing, as the machine was of the open type, and the results are the

more interesting as the tests were made on a single-phase set; if no accurate means had been available for locating the loss, it is quite possible that this loss would have been put down to other causes and no steps taken to eliminate it. Fig. G shows a typical set of retardation curves. The difference in the losses calculated from curves 1 and 2 gives the windage and friction losses and from curve 3 the no-load iron loss is calculated: allowance is made for the excitation loss. Curves 4 and 5 give the retardation at loads of 252 kw. and 450 kw. and this result acts as a check to the calculation of the stored energy of the plant. No reference has been made to obtaining the loss by the measurement of the steam pressure at the initial row of blades of the turbine and obtaining the Willans line. This has given good results and the loss can be obtained without a lengthy run, and the method is found to be very accurate, but precautions must be taken, as in the other methods,

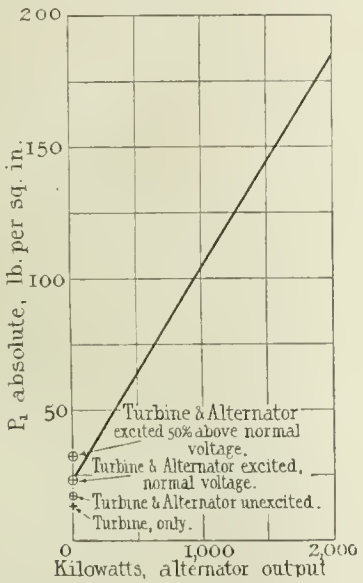



FIG. H.—Curve for 2,000-kw. alternator.

more especially to see that the steam conditions are identical throughout the test. Fig. H illustrates a Willans line obtained on a 2,000-kw. reaction turbine. $P_I$ is the pressure measured at the initial row of blading and is directly proportional to the total quantity of steam passing; as the turbine efficiency ratio measured on $P_I$ is found in practice to be constant, it follows that $P_I$ plotted on the base of kilowatts gives a straight line which is the well-known Willans line. By measuring $P_I$ with the alternator unexcited, excited and uncoupled from the turbine, it is an easy matter to estimate and separate the alternator no-load losses. Results have shown that the anemometer is the best instrument to be used for measuring the velocity of the air. The authors have already shown the disadvantages of the Venturi and Pitot tubes. The electrical methods have similar disadvantages, as it is practically an impossibility to eliminate air eddies, which will certainly give a false reading. I had occasion recently to measure the quantity of air on a test in which the air was heated electrically and then cooled. The quantity of air was checked by means of an anemometer, and also by the heat passed into the air and absorbed by the cooling medium—the results were uniform and gave the air quantity within 4 per cent. I do not agree with the authors that a temporary trunk should be provided, and its use should be avoided if possible. Some of the most informative tests have been carried out with the machines on steady commercial load, and readings taken by the engineer, who was given instructions how to obtain the temperatures under the various load conditions. All he has to do is to measure the temperatures of the air inlet and outlet and take a copy of the station log. Previous to this, of course, the quantity of air will have been accurately measured. I have been able to obtain most interesting figures under these conditions at steady loads up to full load and at varying power factors. In the case of the larger sets now under consideration, separate motor-driven fans will no doubt be employed. With a solid type of rotor where the disturbance due to the rotating parts is small, the quantity of air could be checked by passing direct current through the rotor at standstill, or through the stator, or through both these parts. There are disadvantages attached to this method, but I have no doubt that it will at least be a useful check on the other tests.

**Mr. E. Fawssett:** The author's methods appeal strongly to the practical man, since they allow of the machine being tested under commercial conditions on the actual load corresponding to the specified performance. This is very necessary as the "stray loss" which is the indeterminate factor in other methods certainly varies largely with conditions that occur in normal running, e.g. I have found the stray loss in end-bell heating vary very considerably through the normal range of power factor (unity to 0·7) at constant kilovolt-amperes. I am surprised at the considerable praise given to the anemometer, and also at any maker guaranteeing 1 per cent on any such instrument. I should like to know over what velocity range this held good. Though not seriously affecting its use for the purposes in this paper, the remarks on its inaccurate registration of varying velocities are interesting. I have found such error to be of the order of 5 per cent on a ¼ minute run with velocities varying from zero to a maximum: but I disagree with the authors when they ascribe it to "inertia." Certainly inertia is involved in the meter's overrunning, but it is not the cause of the acceleration and deceleration not balancing, since an induction watt-hour meter has a rotor with inertia but next to no air-braking, and does not exhibit this defect within the limits of accuracy of a careful laboratory test, say 0·1 per cent; rather is the anemometer's failing due to the varying conditions in which the rotor has to work when accelerating in the stream of air and decelerating, the acceleration being dependent on the difference between the wind and vane speeds. I have no confidence in the anemometer, and even curve A in Fig. 4 looks to me as if we may expect considerable errors in its use, wherefore I much prefer the calibrated air-temperature method, especially as no previous data are really necessary since either (1)

the machine can be run up from turbo end, synchronized in, turbo slipped by Messrs. Parsons' method, and the input to the machine measured near unity power-factor with special small ratio current transformers, and the rotor loss added in; or (2) when the fan is separate the machine may stand and have its rotor fully excited from another source, though as this would not exceed one-fifth or so of the whole the temperature rise will not be very large and it will take a long time for conditions to become quite steady.

**Mr. L. H. A. Carr:** I do not care for the use of the term "stray loss" in the sense in which the authors use it. To my mind the indefinite or true stray loss may be divided into two parts, first, the stray loss at no load which is measured with the core loss, and secondly the increase of stray loss when load is put on. The authors use the term "stray loss" to denote the latter part only, and I suggest the term "incremental loss" would be better. In a standard direct-current machine this incremental loss is known to be largely due to the distortion of the flux wave on load, this distortion being accompanied by a higher maximum flux density, and empirical methods can be used with a fair degree of accuracy to predetermine it. With a cylindrical rotor, this distortion should be very much less than with a direct-current machine, since the flux wave can be displaced without much distortion, and I should like to know whether the figures given in Table 6 refer to machines with salient or cylindrical rotors. I should be glad to know if the authors could give any indication of the cause of the stray loss, and whether they are able to give away the secret of how to avoid it by careful design. For example, if a turbo-alternator be imagined, and then the design altered by doubling the air-gap and approximately doubling the rotor ampere-turns, would the stray loss be reduced? The agreement in Table 2 seems to be rather too good, for surely the losses measured by the driving motor include exciter losses which do not enter into the losses obtained from the air heating. I would suggest that there is considerable practical difficulty in holding the anemometer for one minute (as suggested by the authors) over each of 81 squares, due to fatigue of the experimenter and consequent liability to inaccurate placing of the instrument. Has any mechanical arrangement been used for this purpose; and if so, would it not baffle the air? I should be glad to know if the air temperature varies much over the chimney, that is whether the air is thoroughly mixed. This is doubtless interlinked with the uniformity of the velocity over the chimney. I am interested to know that the velocity can be obtained so uniform as shown in Fig. 5. Some years ago I carried out some tests on small fan-ventilated motors with a 6-ft. wooden chimney, but it was found impossible to get rid of a partial negative flow of the air, and so these particular experiments were abandoned. One would be glad to see standard methods of efficiency measurements adopted, as some customers prefer summation of losses methods, and some customers prefer other methods, and while the figure expected for each method is known to the manufacturer it is usually unknown which of them is desired by any individual customer.

**Mr. J. R. Beard:** From the plant user's point of view the paper is very valuable, since there is no doubt that if a simple and accurate method is available for the determination of alternator efficiencies under working conditions the result will be more accurate predetermination of performance and reduced losses. The classic example of this is, of course, the enormous improvement in fan and pump design when the electric motor drive enabled the power inputs to be easily determined. As a result of more accurate predetermination of efficiency it is to be hoped that some reduction will be possible in the considerable margin asked for on the steam-consumption guarantees of turbo-alternators before the penalty and bonus clause takes effect. Increased alternator efficiency is, however, the more important point now that higher load factors and coal costs make economical generation so essential. In rough figures I estimate that in a modern 50,000 kw. station 1 per cent improvement in alternator efficiency would enable at least £4,000 extra per annum to be earned with the same capital and running costs, and in addition there would presumably be a saving in the capital cost due to the less material required for the more efficient machines. Turning to the actual methods of measurement I have three suggestions on which I would be glad to have the authors' comments. (1) In the calibrated air-temperature method would it not be possible to make the calibration by measuring the increase in temperature caused by heating an external resistance (say of the iron grid type) placed in the inlet. The heat losses in such a resistance could be measured with much greater accuracy than the core loss and the method would be equally applicable to tests on site. (2) I have always been attracted by the method of measuring the flow in water turbines by admitting a measured steady flow of salt solution of known strength at the inlet and analysing the outlet water for the amount of salt per cubic foot. Would it not be possible to apply a similar principle to air measurements by admitting a known quantity of inert gas into the inlet? There is no doubt that the passage through the alternator would thoroughly mix the gas with the air and, I believe, the amount of small quantities of such a gas as $CO_2$ can be determined with very great accuracy. (3) I incline to the view that in the future a closed air-circuit method of cooling alternators is, for various reasons, likely to be frequently used, the same air being circulated continuously and passed over some form of water cooler. If this is so, simple measurements of the water circulation through the cooler and its temperature rise would give at once an exact measure of the total losses in the alternator. I was interested in the description of the Roberts micromanometer, since some 12 years ago I tried to construct an instrument on this principle for the measurement of coke-oven gas. I found, however, that the surface tension at the surface of the bubble in the small connecting tube vitiated all my results. In addition to an air bubble I experimented with bubbles formed of various liquids which were not miscible with the main liquid, but without success. Perhaps means have now been devised for overcoming this difficulty with the surface tension. I think it would add to the value of

the paper if the authors could describe the methods adopted for air volume measurements by the National Physical Laboratory in their extensive aeronautical researches.

**Mr. A. Q. Carnegie:** This method of determining the efficiency of an alternator by the temperature rise of the cooling air has been used by Messrs. Parsons at various times for quite a number of years, and although we have often felt that it would be better to use an orifice for the measurement of the air, we have been forced to the same conclusion as the authors, namely, that an anemometer is about the only convenient instrument available. The use of an orifice would be extremely difficult, owing to the very cumbersome air ways which would have to be provided, and it would be ruled out by the fact that the fan system attached to the alternator would not be capable of giving the additional pressure required to pass the air through the orifice. I must say I do not like an anemometer—as an instrument—it is extremely delicate, and it requires very special apparatus for its calibration. I think that in any test such as the authors describe, the anemometer should be calibrated just before use, and should be returned for recalibration immediately after. This, I think, is necessary to provide against the possibility of the vanes having been accidentally disturbed from any cause. The instrument should, further, be calibrated in air of the temperature at which it has to work, as I have known cases in which the instrument ran slower and slower as its bearings became warmed up. The second method, which the authors call the "calibrated air-temperature" method, avoids the necessity for directly ascertaining the weight of air passing, and seems to me to have considerable advantages.

**Mr. W. G. Turner:** The paper gives a very practicable solution of the otherwise almost impossible problem of ascertaining the total losses in large turbo-alternators, and should prove to be of great service to both manufacturers and users of such plant. The remarks which I am about to make are from the standpoint of the latter. A turbo-alternator set is purchased on a guaranteed steam consumption, the accuracy of which can be checked most readily. From this the combined efficiency of the machine is calculated by comparing the steam consumption in lb. per kilowatt-hour with the work which would be theoretically obtainable in an ideal engine working substantially on the Rankine cycle. Hitherto, the checking of the alternator efficiency guarantee has been almost impracticable, with the result that the purchaser has been more or less in the hands of the manufacturer. By the application of the "air-heating" method which enables the otherwise indeterminable stray losses to be included, the alternator efficiency can be accurately calculated. Further, the mechanical efficiency of the turbine can be deduced from the actual alternator efficiency, and the combined efficiency of the machine calculated as above. The method will be undoubtedly of great importance in cases where the turbine and alternator are purchased from separate contractors, in particular the settling of any dispute which may arise regarding efficiency guarantees. In arriving at the efficiency, however, allowance must be made not only for the bearing losses and the loss due to heat dissipated from the outside of the stator, both of which are mentioned, but also for the exciter losses as well as the kinetic energy in the air leaving the alternator. These losses, whilst being small individually, are of appreciable magnitude when taken collectively. It should be noted that a correction has been made in formulæ (2) and (2A) to cover the loss due to heat radiated from the stator. If the plant is tested after erection a deduction must be made for the extra air-friction losses due to the ducts and air filter. In the testing of large machines we are still left with the problem of a full-load run at the manufacturer's works, which to a great extent depends on the boiler capacity and also the facilities for dissipating the electrical energy generated. The test will generally have to be carried out after the machine has been delivered and erected. The apparatus required is simple, but the test is rather laborious, involving, as it does, a great number of separate readings to ascertain the average velocity and temperature. If instead of the separate readings some means could be employed for one reading only in each case, a great improvement would thereby be effected. When, however, it is remembered that the test will not often be required, possibly only once in the life of each machine, the amount of work involved is excusable. The authors do not mention the alternative of measuring the velocity of the air at the alternator inlet, where one would expect a more equal velocity distribution and direction of flow. By means of a circular opening here the velocity readings might be reduced to a series along a diameter only. Measuring at the inlet might be more practicable in the case of machines discharging at the stator bottom which are usually fitted with ducts leading to the outside of the building. This would not, of course, eliminate the necessity of taking a number of thermometer readings at the outlet to obtain the average outlet temperature. It is interesting to note that an appreciable percentage error in arriving at the heat carried away by the air becomes of decreasing importance as the output of the alternator increases, that is as the efficiency rises, and in any case only affects the efficiency by a very small percentage. For instance, if we assume that the actual loss of 336 kw. as obtained by the American Institute method for machine No. 5802 in Table 6 is the correct loss, then the loss of 352 kw. given by the air-heating method for this machine is 4·8 per cent high. Assuming the load on the machine to be 5,000 kw. the true efficiency would be 93·7 per cent, and the efficiency obtained by the air-heating method 93·42 per cent, which is an error of only minus 0·28 per cent. Now that a simple method of obtaining the total losses has been applied it would be interesting to know whether the authors have arrived at any definite conclusion as to the laws of the variation of the stray losses with the load. To enable the formulæ for Method (1) to be quickly evaluated, I have prepared an alignment chart (see Fig. J) from which the kilowatt loss as calculated by the air-heating method, under any condition and for any size of machine, may be obtained by the simple expedient of drawing crossing lines. These charts are very simple to prepare and

might be more often applied. They can be constructed to evaluate complicated formulæ involving a number of variables by a combination of charts connected in threes, the method adopted in this case. In order to explain the working of this chart I give the following example: Suppose V = 16,800 cubic feet per minute, and $T_o - T_i = 71{\cdot}6$ degrees F. and we wish to find P in formula (1). We join 1,680 on the V axis to 71·6 on the $T_o - T_i$ axis, and find that the line passes through 36·4 on the P axis, which multiplied by 10 gives 364 kw. loss. If now we wish to correct this for the variation of air density with temperature and barometric pressure as obtained with formula (2), H being, say, 29 inches of mercury, and the average absolute temperature at the alternator discharge say 570° F., we join 36·4 on the P axis to 29 on the H axis and let the line intersect the ungraduated axis at a point which we will call A. We then join 570 on the T axis to A and produce it to cut the P axis, when we get $35{\cdot}2 \times 10 = 352$ kw. loss. The lines must join values in the order given, because the chart was so constructed. The Centigrade portion of the chart is for use only with formula (2A). I have not dealt with the calibrated air-temperature method as this admittedly is not so accurate as the air-heating method, and, generally, would be used only as a rough test of efficiency under service conditions, rather than in checking the guaranteed efficiency.

**Mr. H. B. Poynder:** A few points occur to me in connection with the paper. In the first place, Tables 6 and 7 show the stray loss or, as I, like an earlier speaker, should prefer to call it, the incremental loss, determined for three different machines at full load by the air-heating method. The incremental loss as thus obtained is, especially in the smallest machine, the difference between two relatively large quantities, so that it will be very sensitive to comparatively small errors in the latter. If now the authors could submit figures showing a number of different values between no load and full load, the plotting of a curve connecting the incremental losses with the current passing would give a very clear indication of the degree of accuracy

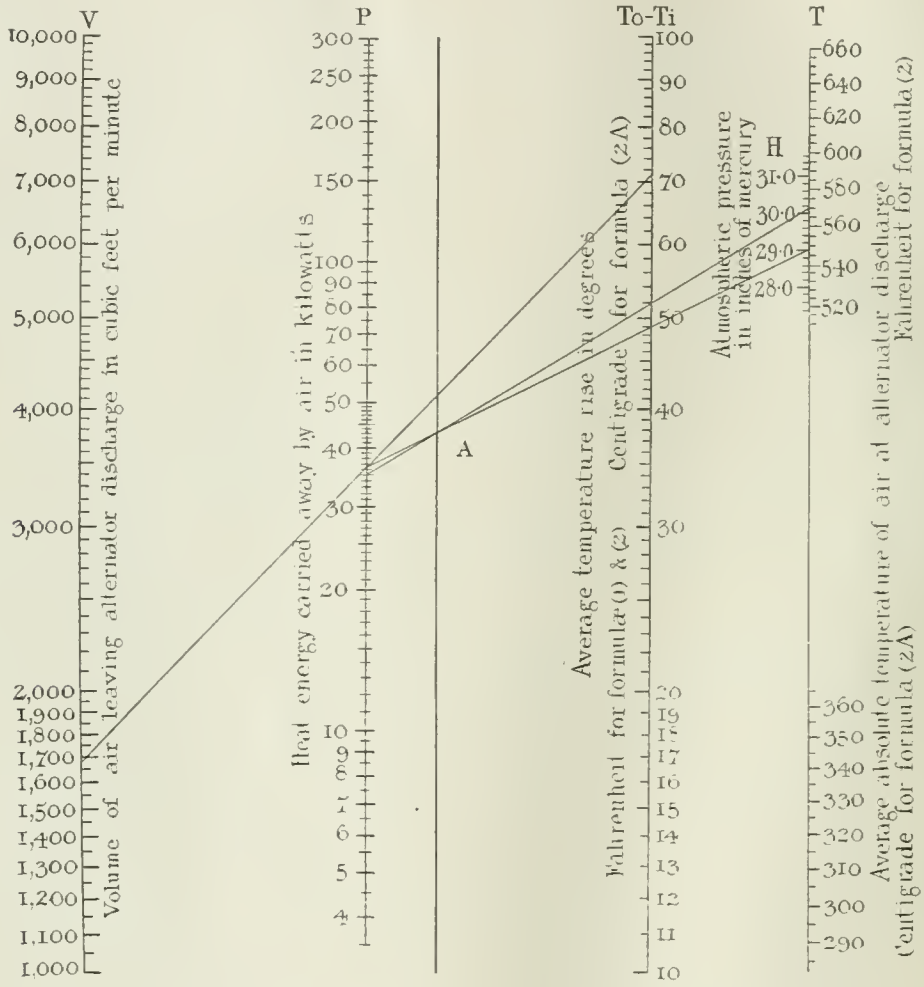



FIG. J.—Chart giving losses in kilowatts as measured by the "air-heating" method.

of the air-heating method; it would, in fact, exaggerate any errors. If the points fall well in a reasonably smooth curve and show zero value for the increment at zero current, we should then have a stronger vindication of the accuracy of the method than could, I think, be obtained by any other means. In addition, the shape of the curve would give us valuable information about the incremental losses. In direct-current machinery they have been found to vary directly as the current squared, and they presumably follow a similar law in an alternator. I think that, from some points of view, an unnecessary mystery is made of the incremental loss. Taking first the case of a direct-current machine, imagine an armature fitted with brush-gear but without a field frame; a certain applied voltage is necessary to force a given current through the armature when at rest. If it is now rotated a higher voltage will be necessary, quite apart from any change in the contact resistance of the brushes. The loss will not exert any resisting torque, which is perhaps more clearly seen if one assumes that, instead of rotating the armature, the brushes are rotated. We have here a relative movement between the armature and the magnetic poles, with consequent hysteresis loss in the iron and eddy-current losses in the iron and copper. If now a field frame is superimposed, unexcited, with the poles symmetrically disposed midway between the armature poles, the reluctance of the magnetic circuit will be considerably decreased and the loss consequently increased, but provided that the number of lines of force are all cross-magnetizing, or in other words that the armature current does not produce any flux through the yoke, there will still be an absence of external torque, and the increased loss demands an increase in the voltage applied. Similarly we may consider an alternator stator without a rotor. If a three-phase voltage is applied to the stator, the hysteresis and eddy-current losses do not set up an external torque; and if the rotor be now inserted and driven synchronously, unexcited, and free to set itself at what angle it likes, there will still be no external torque exerted, although the losses will have been increased through the reduction in the reluctance of the magnetic path. In direct-current machines I have been in the habit of considering the incremental losses as equivalent to a resistance loss for a given winding, speed, and air-gap length, determining the equivalent value in ohms and adding it to the ohmic resistance of the armature, using this convention not only for calculating the loss but also for calculating the voltage drop in the armature. This is based upon the assumption that the main flux is of normal value, and it will be very interesting to hear from the authors how the incremental loss varies with the main flux, that is, whether and to what extent the incremental loss in the unexcited machine is affected by superimposing the main flux. In my opinion if the incremental loss with zero main flux is proportional to the square of the current and causes a voltage drop rather than an external torque, then it is to be expected that the incremental loss with full excitation will have the same characteristics. It should be noted that, if this is so, the real incremental loss is less than the apparent, since the voltage drop due to the real loss should be taken into account in calculating the true value of the main flux. The incremental loss can also be considered to be the difference between the losses due to the main flux and that due to the resultant of the main and armature or stator fluxes, but to calculate it on this assumption requires an exact knowledge of the distribution and maximum values of the resultant flux, which is probably much more difficult than to treat it as a function of the armature ampere-turns, assuming that the latter method gives sufficiently accurate results. The incremental loss has been recognized, and empirical formulæ based upon (armature ampere-turns $\times$ speed)$^2$ have been in use for nearly 20 years by machine designers, and it appears very remarkable that it has not previously been more fully investigated. I trust therefore the authors of this paper will give us an authoritative statement which will carry our present knowledge a very substantial step forward. The only other point which occurs to me is in connection with the method adopted for measuring the temperatures and the flow of air. A previous speaker has referred to the difficulty and trouble involved in taking so many thermometer and anemometer readings. It would undoubtedly be an advantage to be able to get accurate results with a single reading, and it would appear possible to obtain this by the use of three similar multi-wire grids each composed of a suitable resistance material. Calling these A, B, and C, A would be fixed at the inlet and B and C at the outlet, one above the other. A and B would only carry the minute currents necessary to obtain resistance readings, and the difference in their resistances should give a very accurate measure of the air temperature-rise. A current which would be passed through C would be adjusted to such a value that its resistance, and therefore its temperature, are some convenient definite amount above that of B. Grid C being thus maintained at a constant temperature above the air passing through it, the velocity of the air can then be calculated from the number of watts expended in C. This method would not necessitate the use of the screened wire used by Professor MacGregor-Morris, an objection to which seems to be the obstruction caused by the screening, if a multi-wire grid is adopted with the purpose of obtaining true average results. I realize, however, that the above method is subject to error due to obliquity of the stream lines, and it is only by actual experiment that it would be possible to determine whether this disturbing cause has in fact any serious effect provided that the screen is kept well up the trunk and baffles fitted as described by the authors.

**Mr. W. T. Maccall:** Has iron been tried for the electrical method of measuring air velocity, and if so is it satisfactory? In case it is, a network could be used to give the average velocity of the air by a single reading, whereas platinum might be too expensive for this purpose. The Wheatstone bridge method could be used by dividing this network into two sets of wires at right angles and having two similar resistances in still air. Similarly the average temperature of the air could be found by a single measurement of the resistance of a network. In using the anemometer,

what difference is caused in the readings when the air is not moving perpendicular to the cross-section, and is any allowance made for this? Does not the allowance for radiation (and other forms of heat dissipation) from the stator frame vary with the size of the alternator? In particular would it not be a considerably greater percentage for a small machine?

(The authors' reply to the discussion will be found on page 488.)

## North Midland Centre, at Leeds, 8 April, 1919.

**Mr. R. H. Campion:** Undoubtedly this paper will help to bring about a standard method of determining heat losses. The method of measuring the temperature rise and the air flow is a good one. It will help with tests when taken on site. The fact that the losses in some 20,000-kw. sets are something like 1,000 kw. shows that it is necessary to agree upon some standard of measurement; and although this paper gives results on a 5,000-kw. set that has forced ventilation, with the exception of a relatively small amount of heat dissipated from the external surface of the stator all the losses except the bearing losses are carried off by the cooling air. The alternative method is described as the "calibrated air temperature" method. There is another point, that the bearing losses may be determined fairly accurately by measuring the volume and temperature rise of the lubricating oil, and by making a suitable allowance for the heat dissipated in other ways. The method advocated in the paper should be adopted to provide a continuous record of a turbo set when in service, and any foreign matter getting into the air ducts would be detected. There is a point I should like further information about, namely, the effect of filters in connection with the determination of the efficiency of the turbo-alternator. I have tried the cloth and the wet type and have come to the conclusion that a combination of the two will give the best results, but I have not been able to get any further load out of the sets by supplying cooler air.

**Mr. W. M. Selvey:** This paper is long overdue. The method of air calorimetry was first accurately explored by Professor Threlfall in the paper referred to by the authors. As regard other methods, I should like to associate myself with Captain Law's remarks (see page 306). We have both been closely interested in a line of alternators the efficiency of which was adequately determined by these methods. The ordinary acceptance test, however, is often the only opportunity for determining the efficiency of the alternator while running at an ascertained load, and moreover is probably the only occasion in the life of the machine in which it is run under absolutely steady and defined conditions. I have long felt it necessary to make some test, however approximate, of the alternator efficiency which can be determined at the same time as the steam consumption tests. The method of air calorimetry plus that of water calorimetry for the bearing losses is practically the only method available, and what therefore has to be considered is whether this can be carried out with any degree of approximation without entailing elaborate apparatus. I think it can. Fortunately, one has to determine the inefficiency, i.e. the losses, and therefore an error of 10 per cent in the actual measurement only signifies an error of $\frac{1}{2}$ per cent in the actual efficiency ascertained. I do not think it is necessary to have so high an error as 10 per cent in the method outlined by the authors, which I have used myself for a number of years without, however, going into quite such refined details. This refinement can only be carried out if the importance of the determination justifies considerable expense, in which case one would run a test lasting 8 or 10 hours under dead steady load for the purpose. The only occasion I can imagine where such a test would be needed by commercial requirements would be where the turbine and the alternator were supplied as separate contracts, and the total result not being entirely satisfactory it became necessary to determine to what extent each contractor had fulfilled the specification. I have brought with me some curves and figures showing the actual results of anemometer measurements on arrangements similar to Fig. 3. In the cases I have taken I have given the velocities measured by anemometer at 16 places. In the first case the plain opening was used for the discharge, but it was of a fair depth. In the other case an additional trunk was placed on the outlet as shown in Fig. 3. There is certainly a good deal of steadying motion by adding the trunk, but no alternator maker would, I imagine, agree to place the obstructions of expanded or perforated metal in the path of the air current unless the air were supplied by an external fan and the actual water-gauge pressure drop across the alternator had been specified. The simplest way of steadying the flow would be to put a few division plates on very thin tin across the flow, edge on, two sets being arranged at right angles and not necessarily immediately one on top of the other. In the figures I have given for the case without the trunk the greatest variation of velocity from the mean is 26 per cent, while with the trunk added the greatest variation from the mean is still the same, although the general flow is steadier. It may be of interest to state that in a recent test where the actual efficiency of the alternator was stated the following are the figures obtained by the air calorimetric method of measuring the sum of the iron, copper, and windage losses, and by the oil-water calorimetric method of measuring the bearing losses.

| | Half Load % | ¾ Load % | Full Load % | Over-Load % |
|---|---|---|---|---|
| Alternator efficiency (excluding bearings) .. | 90·9 | 92·5 | 94·7 | 95·3 |
| Alternator efficiency (including bearings) .. | 89·6 | 91·6 | 94·0 | 94·7 |
| Efficiency of alternator stated in contract .. | 90 | 92·5 | 94·0 | — |

I give the figures both excluding and including bearings, the amount added for bearings being one-half of the total for the four bearings. I think, however, the heat from the turbine conducted along the shaft really makes the loss in the turbine bearings to be higher than in the alternator bearings, and therefore it is rather against the alternator to add one-half of the bearing losses. It will be seen that the figures show very good agreement. I do not think, however, that this is entirely a perfect method, and had I to make a test in which great importance was attached to accuracy I should endeavour to develop the method used in Thomas' gas meter, viz. of adding a known number of watts electrically to the "unknown" air either before or after the alternator and of measuring the rise of temperature produced by this added energy. Many alternators are now fitted with wet air filters, and it would, I think, be necessary to use two heater resistances, one just past the eliminator plates to make certain of evaporating all the moisture carried over, and a second one fairly near to the alternator for the purpose of adding the "known" watts to produce the required rise in temperature. Temperatures before and after the heater and at the exit from the alternator would have to be taken by a resistance thermometer, say by stretching a number of very fine copper wires on a frame in such a way as to offer no appreciable resistance to the air current, and at the same time well spread about the section to get the average temperature of the air. Such thermometers could be quite well home-made. All that is necessary is some fine copper wire and a good Post Office bridge with a fairly sensitive galvanometer. Not a very large rise in temperature need be caused by the preheat in the air, since temperature measurements by using resistance thermometers are so easy to make that probably only one-tenth of the main rise would have to be caused by the heating coils; that is to say for a 5,000-kw. alternator probably about 25 kw. would make quite a workable test. Very simple calculations would therefore give the actual alternator losses from three temperatures and one volt-ampere measurement of the added watts. I do not think this method could be developed for ordinary commercial testing on site, but it could be very well used for research work or for any special case which may arise, in which the matter is of importance. It would seem by the comparison of the results I have given with the calculations that there is not as a rule much difficulty in predicting with reasonable accuracy what the efficiency of the alternator is likely to be.

**Mr. F. A. Lauper**: Most of us younger designers have not the chance to work on big machines of 1,000 k.v.a. output, and therefore we cannot have so much to say about how to determine these efficiencies. But I am sure we all take great interest in these new and improved methods and we can make use of such information always to some extent also for much smaller units. I think that for pipe-ventilated or forced-ventilated motors, alternators and transformers, the given methods can be used with much advantage. One of the most interesting points of course is that this method enables us to determine more accurately the stray losses. The stray losses are very complicated, especially to a young man with little experience. We cannot find much published information about these losses, although probably many designers have their own approximate methods of how to get at them. We can use a certain coefficient such as is given in textbooks or, better, as found from recent tests on actual machines, but we find that it alters very much even for the same kind of machine built up to the same specifications but at different times. I have tested personally some 20 machines ranging between 200 kw. and 2,000 kw., and found that for motors and alternators of these sizes these stray losses were not so important as those given in this paper for big turbo-alternators, i.e. up to 5 or 6 times the stator copper losses. They usually amounted to only from 20 to 40 per cent of the ohmic losses in the armature. Of course single-phase alternators showed such losses to be as high as 100 and 180 per cent of the armature copper losses. We made our usual tests to get at these stray losses with the short-circuit run; that is to say, we excited the short-circuited alternator until full-load current flowed in the armature. When we have had the chance we have driven the alternator with a calibrated motor also on full load. We found that the figures arrived at in both cases generally agreed fairly well; sometimes they were far out, especially on single-phase alternators and motors. Still they seemed to agree very well for the smaller size. We found, however, that these stray losses on short-circuit must be differently distributed from those occurring on full load and also if the alternator is run as an over-excited synchronous motor. I remember a particular case where the local heating was very marked. The machine in question was a high-speed single-phase alternator with solid poles, and we ran it on short-circuit. For some reason we had to shut it down and dismantle it; I think it was due to bearing trouble. We found then that on one and always the same side the fore-running corners of the pole-shoes were heating excessively, in fact got quite blue, which would indicate a local temperature rise of approximately 250 to 300 degrees C. We polished the pole-shoes again and replaced them. The machine was then at about full load for several hours driven by a calibrated motor. After this run the alternator was examined and the pole-shoes were found to have remained absolutely bright. On repeating the short-circuit test, after only a very short run the pole-shoes showed local heating as previously observed. The stray losses determined from both tests agreed fairly well, but obviously these losses were quite differently distributed in each case and caused local heating on the short-circuit run. I think these stray losses are so complicated and important that those members who have more opportunity should give a little more information about such losses so as to help us younger men to obtain better and more accurate results in the future.

**Mr. A. Imbery**: It would appear that by the addition of the baffle plates and by the reduction in area of the outlet owing to the use of the truncated body, the resistance to the flow of air through the outlet would be increased, thus producing an increase in the

temperature of the air expelled from the machine. If we increase the temperature of the outgoing air, the loss in the iron and copper would more than compensate for the increase in efficiency obtained by the use of the truncated body. Another point is that by reducing the temperature of the air on the inlet side, we should be able to reduce the velocity of the air through the machine and probably save something on the present windage losses, in addition to reducing the iron and copper losses to some extent. I should like to know if any system has been used in this country for ventilation of alternators, where the air before entering the machine is passed through a special form of refrigerator or other suitable apparatus, so that the temperature of the incoming air can be maintained at an extremely low figure. I think that if this arrangement can be carried out satisfactorily the iron and copper losses could be kept at a minimum and it might be possible to obtain an increased overload capacity from the machine with the same temperature rise as at present.

**Dr. S. F. Barclay and Dr. S. P. Smith** (*in reply to the discussions before the North-Western Centre, the North-Eastern Centre and the North Midland Centre*) : As far as possible, the questions will be replied to collectively, and repetition of replies to the discussions before the Institution and the South Midland Centre (see page 313) has been avoided. Further, the remarks of many of the speakers do not call for a reply, but we should like to express our thanks to those gentlemen for their valuable contributions.

*Stray loss.*—Mr. Fawssett's experience that the heating of the end-bell varies with the power factor tends to confirm our view that the difference between the distribution of the heating on load from that on short-circuit is largely due to the phase displacement of the current. This view is further supported by the results of Mr. Lauper's tests. Messrs. Carr and Poynder object to our use of the term "stray loss," but we only employ the term in its generally accepted sense. All the machines of which test results are given had cylindrical rotors with the pole-centres unslotted—in such machines the flux wave may be considerably distorted on unity power factor. The very interesting matter discussed by Mr. Poynder falls outside the scope of the paper, which is intended to deal with the measurement of, rather than with the cause of, stray loss.

*Criticism of anemometer.*—The contributions by Dr. Cramp and others are very interesting. With uniform air flow there is no difficulty in measuring the air velocity very accurately, but the whole problem is whether perfectly uniform flow must be obtained or whether results sufficiently accurate for the purpose can be obtained when an anemometer is used in an air flow that is not quite uniform. Some speakers do not appear to have grasped that great accuracy, say within 1 per cent, is not required. Mr. Fawssett's surprise at the statement that the anemometer we employ is guaranteed not to vary more than 1 per cent, may be due to the fact not being appreciated that this is the error after the correction for friction has been made. This correction is practically constant over the whole range of the instrument and is determined by calibration at the National Physical Laboratory. If this constant correction is ignored, the inaccuracy of the instrument appears to be very considerable, varying in accordance with a straight line law from 100 per cent at about 60 feet per minute to 3 per cent at about 2,000 feet per minute in the type of instrument we employ. With regard to Mr. Carnegie's remarks, it should be mentioned that the anemometer can be readily calibrated and, as seen from Table 3, the one used by us gave very reliable results after two years' use.

*Resistance grids.*—Messrs. Walker, Frith, Beard, Poynder and Selvey appear to favour the use of resistance grids, but only Dr. Walker pointed out the special arrangements needed for mixing the air in the heater. The insertion of the apparatus between the filter and the alternator would often entail considerable expense and inconvenience ; while a rapid variation of 1 degree in the temperature of the air near the power station might cause very misleading results when the loss in the grid increases the air temperature by only 5 degrees, as proposed by Dr. Walker. While we fully appreciate the value of a resistance grid under the steady conditions obtainable in the laboratory, the calibrated air-temperature method is to our mind much better for commercial testing.

*Measurement of temperature.*—Dr. Walker remarks that the difference between the effective and the actual area of the discharge trunk may be considerable, but we have not found this to be so. Experience shows thermometers to be very suitable for determining the average temperature of the air at inlet or outlet with accuracy ; moreover, thermometers are usually available in fair numbers. We have found close agreement between the mean temperature determined in this way with that obtained from the change in resistance of a coil of wire mounted in the air flow, as mentioned in the paper. The proposal to use a large number of thermo-couples has been considered by us, but we preferred to bring out all the ends to a common terminal board whereby any couple could be connected to the indicating instrument at will. Connecting a large number of thermo-couples in parallel is very simple, but theoretical investigation is necessary to show under what conditions correct readings would result. In response to Mr. Carr's request, we have appended the following table to show what variation of temperature over the outlet may be expected when the air flow has been made fairly uniform.

*Manometers.*—Mr. Frith and other speakers raised the question of manometers. The reasons which led us to the conclusion that any of the known forms of this instrument was unsuitable for our purpose have been given in the paper, but it may here be added that during these discussions the most conflicting views on this subject have been expressed. Certainly under existing conditions we could not propose the use of micro-manometers for the commercial testing of turbo-alternators.

*Pitot tube.*—Many speakers have expressed surprise that the various forms of the Pitot tube have been rejected by us in the standard methods of test which we have advocated. We can only repeat, however,

that while the Pitot tube can be regarded as an instrument of precision under ideal conditions, it is greatly inferior to the anemometer under the conditions which exist in turbo-alternators.

*Duration of test.*—This matter has been very prominent in the discussions, but our own experience has not shown the time taken to carry out the tests to be unduly long, nor has the labour involved been incommensurate with the importance of the tests.

Turning now to the other points that have been raised, we think it is regrettable that the method adopted by the B.E.A.M.A., as outlined by Mr. Peck, should not have progressed beyond the conventional method put forward some years ago by the American Institute, and it is hoped that the fears expressed by him will have been expelled by the paper and the discussion thereon. It must not be forgotten that the calibrated-motor method does not provide a means for testing the machine on load. To Mr. Frith we would say that we have no test results which would enable us to form a definite opinion of the suitableness of Professor MacGregor-Morris's instrument for measuring the velocity of the air leaving a turbo-alternator. With reference to Mr. Kuyser's criticism, it must be remembered that the windage and fan losses are not known apart from the bearing losses, and that further tests are necessary to enable us to separate these losses. Consequently, if this additional information is not available—as is usually the case—it is necessary to carry out two tests to calibrate the machine; for example, one test with the rotor unexcited, and the other with a known iron and excitation loss. We concur with Mr. Juhlin in regard to the importance of measuring the losses separately, but a calibrated motor alone is not sufficient for obtaining the stray loss which occurs on load, or the windage plus fan loss apart from the bearing loss. To find these losses, methods such as those indicated in the paper are essential. Though the air volume can be found by the air-temperature method, this determination is not necessary when only the total loss or efficiency is required. The presence of free moisture referred to by Mr. Grime would vitiate the results obtained by any air method, but an error due to this cause is not to be feared with a filter which is working properly. In reply to Dr. Cramp, we would point out that the loss due to radiation is but a small fraction of the whole and that the rule given in Appendix 1 is good enough for most practical purposes. Mr. Rosen will find that reference to the retardation method was made in the paper (page 301). Without a trunk it was found that the results obtained were often unreliable, consequently we think that a trunk ought to be specified in a standard method of testing where the velocity or temperature of the air has to be measured. Mr. Carr criticized the figures in Table 2. We would point out that these were the figures obtained after the necessary corrections had been made, while in every case the rotor was separately excited. Mr. Beard suggested the addition of a small, known amount of carbonic acid or other gas. As far as we know, this attractive proposal has never been tried, but it is doubtful whether the mixing could be thorough with some schemes of ventilation. In any case, simpler methods might be preferable in practice. The Pitot and other tube methods used in aeronautical laboratories for measuring the air velocities in wind channels are very exact, but quite unsuitable for the conditions which we are now considering. We are much obliged to Mr. Turner for his remarks and the chart reproduced in Fig. J. Measurements at the inlet are seldom practicable—in many cases the only opening available at the inlet is the opening to the filter; also the flow at the inlet is often less uniform than at the outlet. In reply to Mr. Maccall's query, we do not know whether iron has been tried in the electrical method of measuring air velocity. Our reply to Mr. Campion would be that, when a filter cools the air, either the temperature rise of the alternator for a given load would be reduced, or for a given final temperature the output from the machine would be increased. Had Mr. Selvey used

Temperatures Taken at Outlet of 5,000-kw. Set.

*Turbine End of Alternator.*

| ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. |
|---|---|---|---|---|---|---|---|---|---|
| 115 | 114·5 | 113 | 111·5 | 109 | 108 | 109 | 110 | 111 | 111 |
| 117·5 | 117 | 114 | 111 | 109·5 | 108 | 109·5 | 111 | 113·5 | 114 |
| 120 | 120 | 116·5 | 113 | 111 | 110·5 | 111 | 114 | 117 | 117 |
| 123·5 | 122 | 119·5 | 117 | 116 | 115 | 115 | 117·5 | 120 | 120 |
| 123 | 122 | 122 | 121 | 120 | 119·5 | 119 | 120 | 121 | 120 |
| 121 | 122 | 122 | 121 | 120 | 120 | 120·5 | 120 | 120 | 117·5 |
| 120 | 122 | 121 | 119 | 115·5 | 114 | 114 | 116·5 | 116 | 115 |
| 116·5 | 118·5 | 117 | 114 | 111 | 110 | 110 | 112 | 113 | 112 |
| 113·5 | 114 | 114·5 | 112 | 109 | 105·5 | 107 | 109 | 109·5 | 109 |
| 110 | 110·5 | 111 | 110·5 | 109 | 107 | 106 | 106 | 106·5 | 106·5 |

*Exciter End of Alternator.*

Note.—All readings taken in about 4 minutes. Temperature did not vary while readings were taken. Discharge outlet of trunk divided into 10 × 10 = 100 squares.

the precautions prescribed, we think that he would find no need for the alternative grid method. To Mr. Imbery we would say that the restrictions in the trunk did not affect the air flow appreciably. If a cooler were used, it would doubtless be possible to reduce the volume of the cooling air, but it is questionable whether this would have any marked effect on the losses.

In conclusion we should like to express our appreciation of the very helpful discussions which have followed the reading of the paper before the Institution and four Territorial Centres, and we earnestly hope that the wide interest shown in the subject will result in the adoption of a method for the determination of the efficiency of the turbo-alternator which is based on the measurement of the actual losses and not on conventional quantities.

# PROCEEDINGS OF THE INSTITUTION.

## 631st ORDINARY MEETING, 10 APRIL, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 3rd April, 1919, were taken as read, and were confirmed and signed.

A vote of condolence was passed with the family of the late Sir William Crookes, O.M., F.R.S., Past President, the members standing in silence.

Messrs. J. R. Bedford and E. Eugene-Brown were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

### ELECTIONS.

*Members.*

Bell, Frederick John.
Gray, Andrew.
Mason, Charles Edward.

*Associate Members.*

Adkins, Frederick Sydney.
Austin, Nathan John.
Bayley, Benjamin Croft.
Bentley, George William.
Bowley, Edward Ernest.
Burton, Arthur Cooksey.
Cameron, Ernest Gordon.
Chaytor, Henry Joseph
Christmas, Ernest Napier.
Clark, Frederick George.
Edwards, William Douglas.
Fenton, Herbert.
Gaccon, Evan Charles.
Gerrard, Herbert Rueben.
Grey, Arthur Wallace.
Healy, Henry William.
Hill, Ernest William.
Hudson, James Barcroft.
Hutchings, Arthur.
Kernick, Henry Williams.
Lawrence, Walter.
Lewsley, John Wilfred.
McDonnell, Edward Clement.
McKie, James William L.
McLachlan, Dugald Henderson.
McLare, James Porteous, Capt., R.A.O.C., B.Sc. (Eng.).
Mann, George Henry.
Martin, Thomas Noonan.

*Associate Members*—continued.

Mason, David Meredith.
Mavor, John Bridie.
Molloy, Vincent L.
Palmer, William George.
Paton, Alfred Maurice, B.A., B.Sc.
Pausey, Ernest Bernard.
Pletts, John St. Vincent.
Rattenbury, Grahame.
Roworth, George Ernest L.
Scott, Ernest William.
Smart, James Henry.
Smith, Albert.
Smith, George Casewell.
Southern, Joseph Heaton.
Stamp, James Ernest.
Sweetinburgh, Alfred Weight.
Townley, James William J.
Waite, James Nixon.
Walker, Laurence Gaston.
Wardell, Thomas.
Warner, Herbert Theobald.
Wintle, Harry.

*Associates.*

Faraker, Frederick Cecil.
Johns, Morgan Jones.

*Graduates.*

Adyanthaya, Nitte Mahaling, B.Sc. (Eng.).
Allan, John Edward.
Bakeseſ, Samuel.
Browne, Clarence Fishburn.
Brydon, Sydney, M.Sc.
Crimp, William Norman, 2nd Lieut., R.A.F.
Crowther, William Reginald D., Commdr. R.N.
Dale, James Floyer.
Davies, William Barron.
Frost, Thomas George.
Hardy, William Cornelius G.
Holliday, Wilfred.
Humphreys, Albert.
Love, Charles Reginald.
McGuire, Alexander Thomas.
Rankin, John Stanley.
Rowe, Benjamin.
Skinner, Leslie Carl.
Stacey, Arthur Cecil.
Vince, Sydney James.
Wilson, John, Capt., M.C.
Woods, Alfred, Capt., R.F.

*Student.*

Scott-Taggart, John.

TRANSFERS.

*Associate Member to Member.*

Allingham, Gerald Carlyle.
Burgess, William Anthony A.
Gott, Arthur Edgar.
Lamb, Harry Cromwell.
Lindsay, Alexander.
Rattey, Clifford Clare.
Salt, Charles William, Capt., R.E.
Shaw, Wilfred.
Shipley, John Franklin.
Smith, Stanley Parker, D.Sc.
Wright, Johnstone.

*Associate to Member.*

Gray, James Hunter, K.C.
Webb, George Arthur.

*Associate to Associate Member.*

Avery, Alfred Henry.
Bell, William.

*Graduate to Associate Member.*

Andrews, William Frederick.
Christian, David Adam.
Girdlestone, Horace.
Groom, Harold Robert L., Capt., D.S.O., M.C.
Jenkins, John Sefton
Tabossi, Hector.
Tyler, Arthur Stewart.

*Student to Associate Member.*

Heslop, James Mark.
Kinnaird, James Aitken.
Robertson, James Nisbet.
Tomlins, Frank Charles.
Whitaker, Lionel Bertie.

A paper by Mr. R. J. Kaula, Member, entitled "Notes on Surface Condensing Plants, with special reference to the requirements of Large Power Stations" (see page 440) was read and discussed, and the meeting adjourned at 7.55 p.m.

## 632ND ORDINARY MEETING, 21 APRIL, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 10th April, 1919, were taken as read, and were confirmed and signed.

A paper by Major A. C. Fuller, R.E., entitled "The Fullerphone and its application to Military and Civil Telegraphy" was read and discussed, and the meeting adjourned at 8.5 p.m.

## 633RD ORDINARY MEETING, 1 MAY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 24th April, 1919, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. F. B. O. Hawes, F. Pooley and R. W. Hughman were appointed scrutineers of the ballot for the election of new members of Council.

The President announced that Mr. J. J. Fahie had offered to present to the Institution a collection of papers, letters, MSS., etc., back dating to 1805, and also a number of engravings and photographs of old telegraph apparatus (see Institution Notes No. 11, page 30, May 1919), and that his generous offer had been accepted by the Council.

A lecture on "Magnetic Storms" was delivered by Dr. C. Chree, F.R.S., and, on the motion of the Chairman, a vote of thanks was accorded to the lecturer.

The meeting adjourned at 7.15 p.m.

## JOINT MEETING WITH THE IRON AND STEEL INSTITUTE, 8 MAY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

The chair was first taken at 2.30 p.m. by Mr. E. Schneider, President of the Iron and Steel Institute, who, after some introductory remarks, vacated it in favour of Mr. C. H. Wordingham, C.B.E., President of the Institution of Electrical Engineers.

After a few remarks by Mr. Wordingham in response to Mr. Schneider, the following papers were taken as read and were discussed:—

J. Bibby: "Developments in Electric Iron and Steel Furnaces."
W. K. Booth: "The Booth-Hall Electric Furnace."
H. A. Greaves: "Application of Electrical Energy to the Melting of Metals."
R. G. Mercer: "Electric Furnaces in the United Kingdom, 1918."
A. Sahlin: "A New Type of Electric Furnace."
V. Stobie: "Large Electric Steel-Melting Furnaces."

The meeting adjourned at 5 p.m.

## 634TH ORDINARY MEETING, 14 MAY, 1919.

(Held in the Rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 1st May, 1919, were taken as read, and were confirmed and signed.

Major J. Erskine-Murray, R.A.F., Member, then delivered a lecture on "Wireless in the Royal Air Force." A vote of thanks to the lecturer, proposed by the Chairman, was carried with acclamation and the meeting adjourned at 7.15 p.m.

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# LARGE BATTERIES FOR POWER PURPOSES.

By E. C. McKinnon, Associate Member.

(*Paper first received* 30 *October*, 1917, *and in final form* 12 *January*, 1918; *read before* The Institution 25 *April, before the* North Midland Centre 12 *February, before the* North-Western Centre 26 *February, and before the* South Midland Centre 17 *April*, 1918.)

Synopsis.

Introduction.—Evolution of large batteries; advantages of competition, hindrances to expansion of the battery industry, more particularly absence of standards; appeal for an attempt at standardization.

Battery-room Design.—Aspect, ventilation, floors, walls, ceiling, fixtures, illumination, temperature, conductors, conductor supports, gangway platforms, accessories, stillage.

Standardization.—Design of cells; specifications—analysis and recommendations; tests; maintenance agreements.

High-tension Batteries.—Special features and precautions; Stockholm-Saltsjöbaden Railway; Lancashire and Yorkshire Railway (Manchester–Bury).

Central Station Batteries.—General principles and practice; a description of the Eagle-street battery (Metropolitan Electric Supply Company).

Stand-by Batteries.—Special features and design; stand-by battery at Detroit, Michigan; operating instructions for stand-by batteries; stand-by batteries applied to alternating-current systems; Newton substation scheme, Boston.

Working Results.

Control of Large Batteries.—Continental, American, and British practice; boosters; end cell switches and their functions, American types, British types.

Future Aspect relative to Large Batteries.

## Introduction.

A battery can only be termed large by comparison with others. The apparently large batteries of 20 years ago were small compared with some of those installed in recent years. Really large batteries are still uncommon in this country, but there are sufficient to enable one to study the design, management, working conditions, and results obtained, and to appreciate that batteries can be successfully designed and built for almost unlimited capacity.

Large batteries have been developed in this country mainly as a result of healthy competition between British battery companies. More progress would have been made but for many obstructing factors, such as :—

(*a*) Irreconcilable prejudice against batteries.
(*b*) Difficulty in providing the necessary capital.
(*c*) Attitude adopted by Government Departments.
(*d*) Reluctance to allocate adequate space to batteries.
(*e*) Inadequate training of engineers.
(*f*) Misconceptions about batteries, their functions, etc.
(*g*) Lack of technical supervision over battery operators.
(*h*) Indifferent working conditions.
(*i*) Want of appreciation of the possibilities obtainable with batteries.
(*j*) Absence of standards.

It is impossible in this paper, for reasons of space, to consider the various points in detail, but the absence of standards is a distinct deficiency, and the author advocates an investigation into the possibility of drawing up suitable standards for battery specifications, design, method of testing and maintenance agreements.

## Battery-room Design.

The conditions under which the battery will be operated form a most important factor in the results obtained.

*Aspect.*—The aspect of the room is quite important. Powerful sun-rays striking direct on portions of the battery will cause irregular working, the level of the electrolyte will vary, the specific gravity of the acid will be uneven, the chemical activity will be greater in some cells than in others, and it will be necessary to replenish with water more frequently. A line of

open windows or louvres facing the direction of the prevailing wind may be useful for ventilation, but if chemical fumes, grit, soot, chalk, or lime thereby find access to the battery they are a source of trouble.

*Ventilation.*—Ventilation is certainly important, but it should be confined mainly to the removal of gases. Strong currents of air tend to drive off some of the acid spray which would otherwise be trapped by the spray arresters. They also induce abnormal evaporation of the electrolyte and unless uniformly distributed they are liable to set up uneven shrinkage of woodwork about the battery—containers, stillage, etc. Wherever there is a need for forced ventilation it is preferable to draw out the air, as the incoming air can be readily cleansed and the exhaust can be passed through a draught chamber equipped with acid filters or separators.

*Floors.*—There is such a wide range of opinion as to the design of battery-room floors that the author hesitates to advance any rigid recommendations in this respect. The matter is simplified if the battery room is a single-story one, in which case concrete or compressed ashes form a suitable base: with the latter, however, spontaneous combustion must be guarded against. In two or more storied buildings the trend is to employ reinforced concrete as a base.

What to place on the base is more problematical, and the choice ranges between cement, tar, bitumen, asphalt, vitrified bricks or tiles, wood blocks, and rubber sheeting. It is difficult to make an acid-tight floor with tiles or bricks set in cement. Asphalt is an excellent acid-proof covering, but it is not suitable to bear heavy concentrated weights, especially in a warm room. The best floor which can be used is probably one of vitrified brick or tile laid on concrete, with the joints pointed with an acid-resisting, asphaltic, or bituminous compound. Tiles 8 in. or 9 in. square by 2 in. thick are preferable because this reduces the amount of jointing to be pointed. The compound should be of such a quality that it will not become brittle with high or low temperature, but will remain plastic at all times. The tiles should be laid about $\frac{1}{4}$ in. apart so as to provide proper space for pointing, and the tiles must be thoroughly dry otherwise the compound will not adhere. In cases where the battery room is not directly on the ground the extra precaution should be taken of placing a layer of felt or paper treated with acid-resisting compound on the top of the concrete. Cement will not resist acid for long, but modern batteries do not weep acid to any appreciable extent, and a cement floor will be found thoroughly durable if periodically swilled down with water.

The slope of the floor is important and discussions arise from time to time as to the merit of cross camber or through slope compared with a dead-level floor. The author advocates a gradual slope of 1 inch in 10 feet, from end to end of the room, or from each end to the centre terminating in gutters, and no fall or slope across the room. Gutters or channels along each gangway are superfluous, and unless covered by wood gratings are a source of danger to the operators. Any supports below the lowest tier of insulators form part of the building and not part of the battery. These supports of whatever description should terminate in a dead-level surface of uniform height. Wooden floor plates at right angles to the stillage have the advantage of distributing the weight, but are an obstruction when swilling down the battery room. Concrete pedestals, vitrified tiles, bricks, blocks, or truncated cones, wood blocks with lead aprons or glass drip trays are all available to select from as a useful means of support and levelling.

*Walls.*—The construction of the walls is not of minor importance. Lime-washed walls are not very suitable, as the lime flakes off and makes the battery untidy, apart from the neutralizing effect of the lime on the acid in the cells. Mortar setting does not withstand the acid very well. A cement facing is good, especially if given a heavy coating of light coloured paint. Vitrified bricks make a sound durable job, but better appearance is obtained from glazed bricks or tiles.

*Ceiling.*—The type of ceiling or roof of a battery room is of importance. Whitewashed ceilings are even more objectionable than whitewashed walls; metal work, however high the roof and however carefully painted, deteriorates quickly, shedding rust, ferric sulphate, or zinc sulphate, as the case may be, on to the cells beneath. Ferro-concrete has the objectionable quality of "sweating." For appearance and durability a wooden ceiling painted or varnished has much in its favour.

*Fixtures.*—A most unfortunate habit prevails of installing the battery and then setting to work to fit lamps, ventilating ducts, and supports for conductors, all of which could and should be done before the battery is assembled. If a battery is on an upper story it is better to be able to raise the goods through a hatchway in the floor rather than raise the goods to the battery-room level outside the building and then drag them in through a window or opening. Overhead lifting tackle should therefore be provided, and in addition sufficient working space to land the goods and to carry out repairs should be allowed for in fixing the dimensions of the battery room. Adjacent to this working space a sink should be fitted, and there should be a suitable water supply for cleaning out purposes.

Facilities for replating and cleaning out a large battery should be considered when designing the room. Waste acid and sediment might be conducted to a special length of waste pipes constructed of lead or terra cotta, and carried outside the building to a convenient position for handling the acid and trapping the sediment, which has a value at least 25 per cent that of the old battery plates per ton. Disposal of the waste acid is a problem which must be dealt with. The contention occasionally set forth that waste acid must be neutralized before passing to the drains is impracticable when dealing with large quantities. A complete water-supply system should be designed for the provision of distilled water including the still, storage tanks, and the distribution pipes terminating in valves or taps. It is also useful to provide an effective acid pump with the necessary delivery pipes to obviate the haulage of carboys up to the battery room.

*Illumination.*—Good illumination in a battery room is required, but for inspection work a dark room with light concentrated on one cell at a time is found advantageous. Lamp fittings should be of porcelain and

should be assembled over the passages and not directly over the rows of cells. Portable lamps are most serviceable if protected with wood or ebonite shields. The connections should be rubber covered, and wall plugs and sockets should be of porcelain.

overworked at the expense of their life. There is also a tendency for the woodwork to shrink at high temperatures. On the other hand at low temperatures the capacity is temporarily lowered, the mean voltage on discharge is lower, and the mean voltage on charge

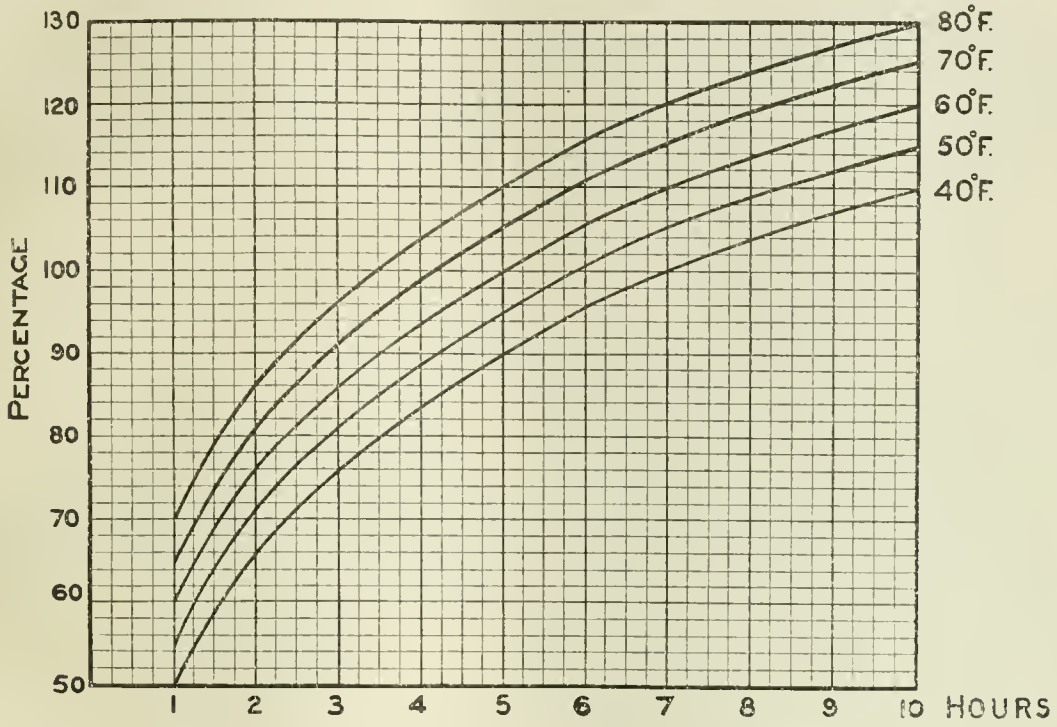


FIG. 1.—Percentage capacity of Planté cells, at various temperatures.

*Temperature.*—Extremes of temperature do not occur in this country to an extent which renders it necessary to equip battery rooms with heating apparatus or cooling fans, but the effect of temperature on the capacity, efficiency, and life of a battery should not be overlooked.

is higher. This results in a decreased efficiency. Further, if the pressure is lower on discharge, more current is required for the same number of watts. This increased current involves a discharge from the battery at a rate at which it yields a lower capacity and to

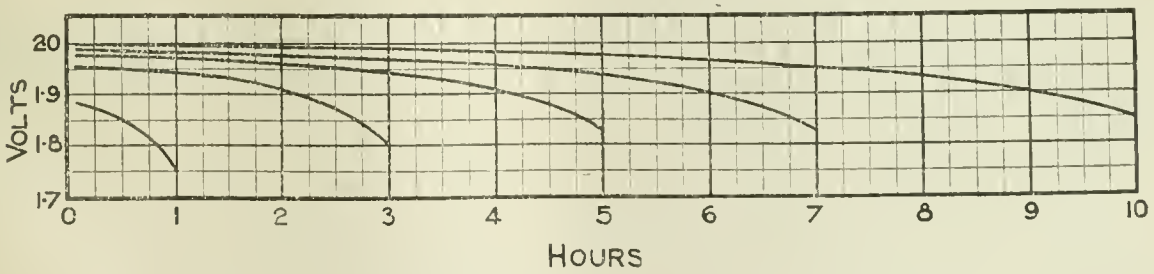


FIG. 2.—Fall in voltage of cells, at different rates of discharge.

The objections to very high temperatures are mainly that any impurities in the battery are more active at high temperature, evaporation is excessive, the gas bubbles float in the air more readily, any acid spray dispersed concentrates more rapidly, and the strong acid attacks wood and metal work. The capacity of the battery is increased, consequently the plates can be

obtain even this capacity it may be necessary to run the battery down to a lower voltage.

The curves in Figs. 1 and 2 illustrate these points. In Fig. 1 the capacity of a Planté type stationary cell is shown at different rates of discharge expressed as a percentage of the 5-hour rate, and the effect of temperature on the capacity is indicated. Fig. 2 shows char-

acteristic curves of fall in voltage at various rates of discharge. The temperature effect on these curves is not shown but is appreciable, amounting to 0·001 volt per degree Fahrenheit on the initial voltage at the 10-hour rate of discharge.

*Conductors.*—The choice of material used as conductors may be left to the consideration of prevailing prices and local conditions. Bare copper rods for efficiency, appearance, and ease in assembling are readily first favourite with many. Bare aluminium is a strong competitor on the question of cost, but is less satisfactory in appearance and manipulation. Insulated cables are going out of use more and more wherever possible. Taped and braided cables are unsuitable. Lead-covered cables are cumbersome. India-rubber covered cables are quite satisfactory except as regards fire risks and their unwieldiness in heavy sections. If paint is employed to protect the copper or aluminium conductors in a battery room several coats should be applied, but owing to intermittent expansion and contraction there is always a tendency for the paint to crack, and concentrated acid—the residue of acid spray—will penetrate a hair's-breadth crack and play havoc with the conductors. The most satisfactory form of protection is lead covering with the further protection of a coat of grease or paint, or alternatively a coating of vaseline on the bare copper or aluminium, occasionally wiped off and renewed.

*Conductor supports.*—These are now designed in many patterns. Several methods of support appear to be thoroughly satisfactory. Where possible the conductors may with advantage be supported by iron suspension rods and hangers from which they may be insulated by split porcelain insulators designed for actually clamping the conductors in place. This is necessary because of the enormous forces which are exerted between parallel conductors carrying very heavy currents.

*Gangway platforms.*—Large batteries, either as regards number of cells or ampere-hour capacity, usually require gangway platforms for purposes of insulation or to bring the operator's head and shoulders above the level of the cells. An open lattice or rack pattern is satisfactory, but the author prefers a solid flooring laid on longitudinal joists. These platforms should not be of a flimsy character, and for the purpose of cleaning the insulators and floor, the platforms should be made in closely-fitting removable sections.

*Accessories.*—To complete the equipment of a battery room it is advisable to provide—

A chemical testing set to check the purity of all water and acid used in the battery.
An ambulance set for prompt use in the event of burns, cuts, or acid splashes.
Apparatus for lead burning.
Instruments for testing cells.
Apparatus for bridging over one cell.
Acid pump.
Tools for cutting out and repairing plates
A suitable selection of spares.

*Battery stillage.*—Fig. 3 shows different styles of stillage in vogue. The insulated earthenware pillars shown in the same figure form an excellent alternative to wood stillage. Iron or steel girders and cast-iron standards—favoured items in specifications 15 to 20 years ago—have now rightly been abandoned as unsuitable for supporting a battery. Where wood stillage is employed it is advisable to split up the lengths into 18-ft. sections to improve insulation. It is also advisable to insert transverse gangways where the battery rooms are built very long. No rule can be laid down, but 40 feet is found to be a convenient approximate maximum. Although frequently specified, it seems quite unnecessary to determine the width of the gangway by the length of the cell on either side of it. If space is limited, gangways 2 ft. wide are just sufficient; gangways 3 ft. wide are comfortable, and no gangway need be more than 4 ft. wide. Where cells are placed in double rows it is advisable to have at least 9 inches between opposite cells in order to clean down and replenish the protective coating of the containers. In batteries composed of very large cells this width should be increased to at least 18 inches.

## Standardization.

Although competition has led to some attempt at standardization by battery makers, much remains to be done, and the desired object will never be achieved until the matter is taken up by representative bodies. Four main sections call for agreed-upon standards.

(*a*) Design of cells.
(*b*) Specifications.
(*c*) Tests.
(*d*) Maintenance agreements.

### (*a*) Design of Cells.

When dealing with design of cells, more especially those constituting large batteries for power purposes, the items may be divided into two categories:—

(1) Open to standardization,
(2) Variables.

The items to be standardized embody—

*Plates.*—Minimum weight per ampere-hour capacity at a fixed rating, preferably the 5-hour rate; thickness; method of suspension; distance between plates; height above and below plates; distance at end of sections.

*Electrolyte.*—Specific gravity and bulk in proportion to ampere-hour capacity at a definite rating.
Thickness of lead linings.
Weight of channel bar per unit length.
Cells centres or pitch of cells.
Insulators.

Items classified as variables include:—

*Separators.*—Type, and method of support.
Method of wedging plates.
Method of arresting spray.
*Containers.*—Construction (solid or panel); type of timber; method of lining, and wedging up; class of paint.

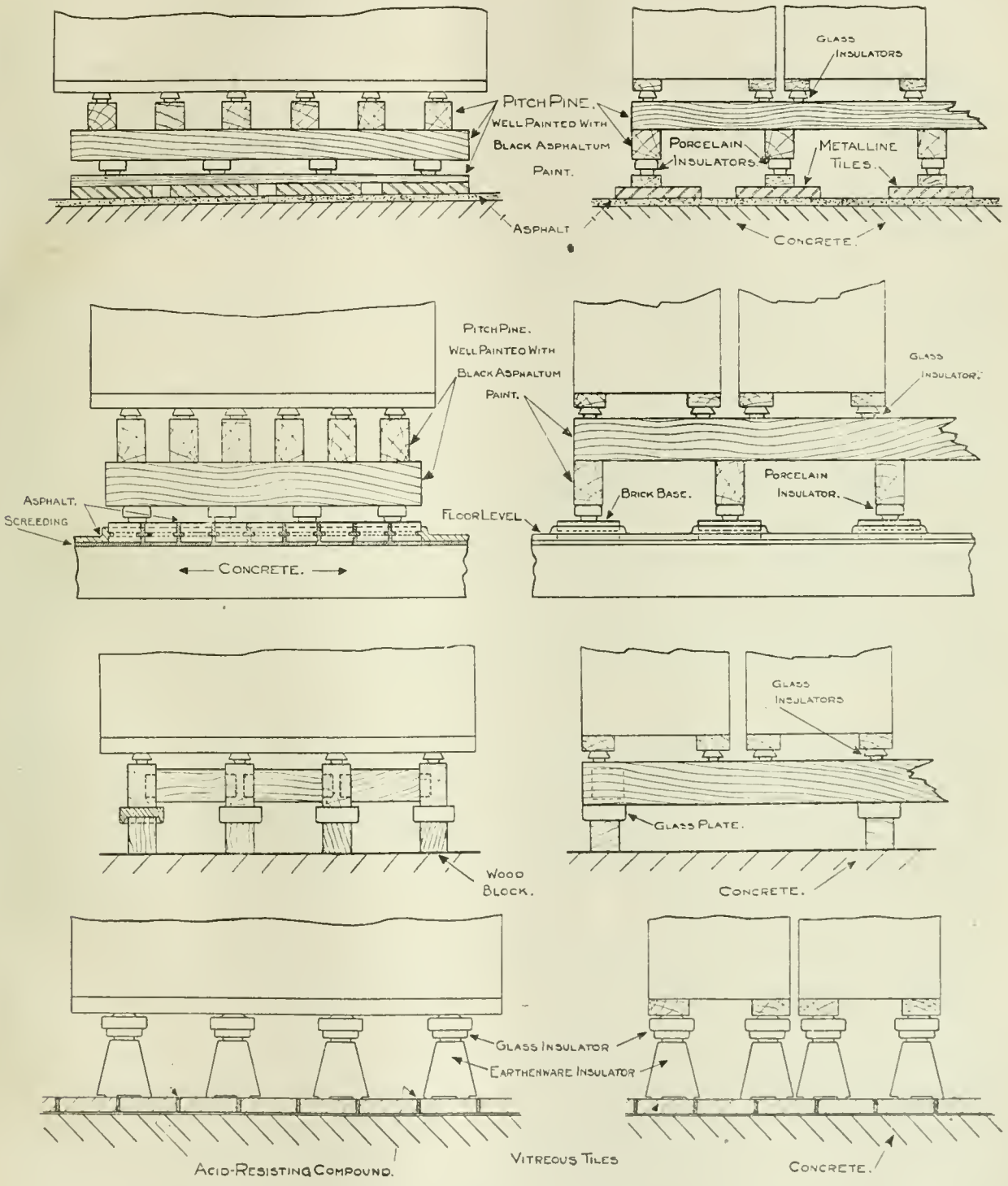


Fig. 3.—Stillage for Large Batteries.

(1) *Battery parts open to standardization.*

*Containers.*—It may be accepted that all large batteries will be assembled in lead-lined wood boxes, but whether these should be plain dovetailed or skew dovetailed, panelled or flush, is a detail best left to the manufacturer. It may also be accepted that no corrodible metal fastenings shall be employed, except in certain vital parts, and then only if completely immune from attack by acid.

The thickness of lead lining need not be more than $3\frac{1}{2}$ lb. per square foot. Provided that the battery is properly insulated and that the positive plates are not allowed to come into contact with the lining, no depreciation through peroxidization will occur. Similarly if the lining is protected from any action by wood acids and is made of chemically pure sheet lead, no pitting will take place. Drainage between the lining and wood container is useful to carry away any condensation moisture, or to reveal a leaky lining quickly instead of holding the leakage acid in the wood container to the serious detriment of the timber.

The relative height of the container to the height of the plates may easily be standardized. Excessive freeboard above the plates would have serious drawbacks, as the necessarily long plate lugs alternately covered by electrolyte and exposed to the atmosphere would be liable to disintegration and consequent breaking of the supporting and current-carrying lugs if these were of soft lead as distinct from antimonial lead.

The amount of space below the plates should be deep enough to avoid frequent removal of the sediment (or trouble through electro-chemical action on the lead linings will arise), but not so deep that the acid in the electrolyte gradually settles down at the bottom of the cell.

The space at the end of the plate section might quite definitely be standardized. Some space is desirable to keep the negative plates from the lead linings (otherwise trouble arises through reduction of the waste products into spongy lead) and also to obtain the readings of the specific gravity of the electrolyte. The practice frequently met in early batteries of fitting an outlet to the containers for use during overhauling has rightly become practically obsolete.

*Plates.*—The actual shape of the plates is a matter which calls for too much difference of opinion to standardize, but the thickness of the plates can be agreed upon, and the minimum weight in pounds per ampere-hour capacity at a definite rating can be fixed in consultation with the battery makers. It might also be possible to agree upon a range of standard widths of plates in order to ensure a common pitch or distance between cell centres. The dimensions and shape of the supporting and current-carrying lugs do not involve any controversy, and they also might be standardized, and thereby ensure that a replated battery will still present a sound engineering design irrespective of the make of plates.

*Plate separation.*—The distance between the plates determines the bulk of acid, the length of the cell, and the range in the specific gravity of the acid on discharge. If the thickness of the plates and the separators be standardized, then the battery user is able to requisition plates of any make for renewals.

*Channel bars.*—Having established a standard for the pitch of cells and the width of plates, it is possible to standardize the dimensions of the channel bars and agree upon a fixed weight of these bars per unit length.

*Cell insulators.*—There is no reason why these should not be standardized, at least as to dimensions and design, assuming that British manufacture is stipulated. The number of manufacturers in this country is very limited, but it is worth noting that British-made green-glass insulators are in every way superior to foreign makes.

*Electrolyte.*—The quality of the electrolyte is at present met by the expression "suitable for use in storage batteries." A specification might be drawn up by a Standards Committee bearing in mind that some of the Government departments have already put their house in order in this respect. Not only is the quality of the acid open to standardization, but the normal working specific gravity of the acid in large stationary batteries can be fixed without any difficulty. The bulk of acid for a given ampere-hour capacity at a definite rating is almost fixed by the above points, and may therefore be standardized.

(2) *Variables.*—It may be thought that so many items are open to standardization that the variables are insignificant, and all batteries would consequently be alike. This is not the case, for there would always be master patents in the hands of one or other of the manufacturers, and workshop recipes, processes, dearly bought experience, and reputation would all remain as jealously guarded as heretofore.

*Separators.*—One of the most important improvements in modern storage battery practice is without doubt the practical adaptation of wood diaphragm separators. This involves the use of selected timber only, and an effective process to eliminate the wood acids which otherwise would disintegrate the plates, also any resin which would obstruct porosity. Wood separators cannot be standardized in detail owing to the various patents covering their manufacture and treatment, but a stipulation of their general employment in large batteries is almost a foregone conclusion. The method of holding up the separators and of wedging the plates, if of the pure Planté type, must be considered "variable" details.

*Construction of boxes or containers.*—This is also a subject on which opinion is divided. The present designs run on two well-established principles; namely

(1) Panel type.
(2) Solid wall type: (*a*) straight dovetailed, (*b*) skew dovetailed.

Cells constructed on either principle are giving satisfaction in service, but panel boxes, though more expensive on first cost and taking up more floor space, appear peculiarly adapted for really large batteries. The durability of battery containers is based upon the class, quality, and dryness of the timber used, the method of construction, working conditions, and especially the protective paints. The combination

of cheap timber and expensive paint will give better results than expensive timber and cheap paints. This question of a protective paint is of far greater importance than engineers appear to realize. The paint should be heavy bodied, acid-proof and non-evaporative. These qualities provide an air-tight coating for the timber which should prevent shrinkage and warping. Additional precautionary measures are to avoid strong air currents around the battery, and to serve the containers periodically with linseed oil.

*Container linings.*—There are two distinct methods of building up the linings—the mitred type, and the block bottom type—each of which has its advocates, but the question of cost is liable to be placed before that of efficiency.

For very large cells the author advocates the mitred method in preference to the block bottom type, but not to such an extent as to recommend that it be standardized in specifications

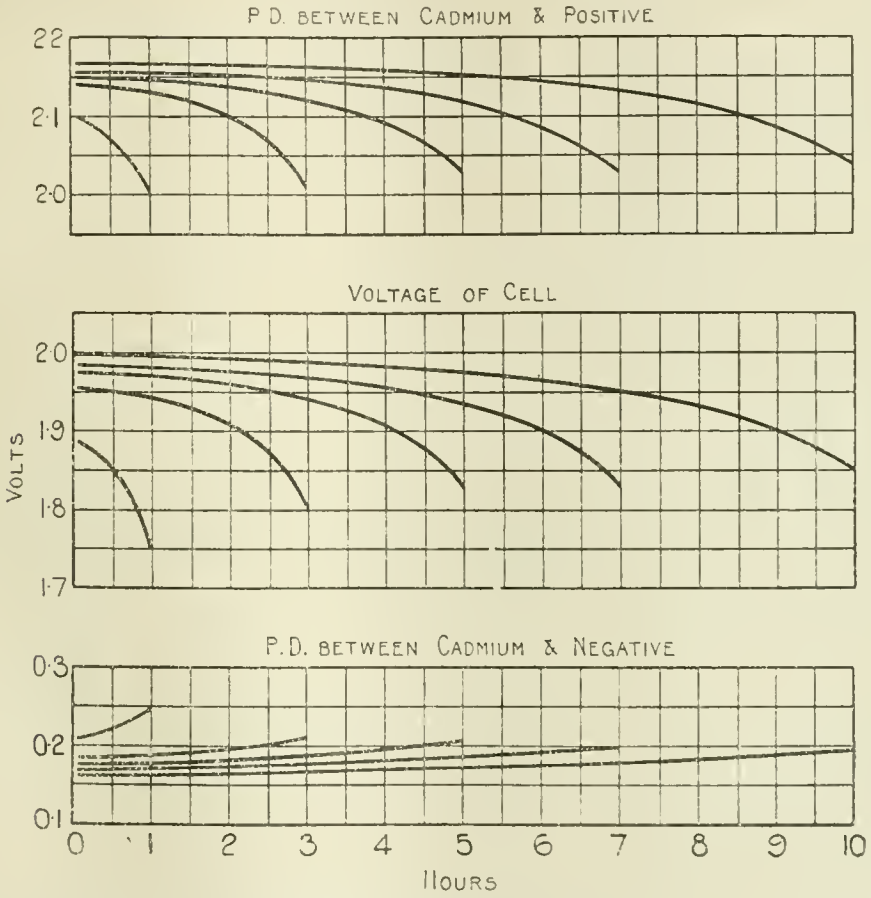


FIG. 4.—Curves showing voltage of cell during discharges at various rates with cadmium readings of positive and negative elements.

### (*b*) SPECIFICATIONS.

The Table on pages 500 and 501 has been compiled from specifications issued during the past five years to show the wide variation in specified points, almost all of which might very well be standardized. There is some information to which everyone will agree; for instance, the number of cells for a given busbar voltage; the final voltage per cell at any given rate of discharge; the percentage capacity at various ratings taking the 5-hour rate as 100 per cent; the ampere-hour efficiency of the battery; the watt-hour efficiency of the battery; the normal and maximum charging rates expressed as a percentage of the 5-hour capacity; the maximum difference of potential attained by the battery on charge. Add to these the points open to standardization in battery design and an equitable method of testing, and the battery specification emerges as a tangible technical proposal instead of a collection of irrelevant and inconsistent stipulations.

Should the author's proposals *re* standardization be taken up and put into concrete form he advocates that the specification be revised at least every three years. This is important because advances in storage-battery design have not reached finality, and the makers now labour under the handicap of having to conform with specifications in several instances drawn up many years ago and obviously out of date in important details.

TABLE GIVING AN ANALYSIS OF A NUMBER OF BATTERY SPECIFICATIONS ISSUED DURING

| | | CORPORATIONS AND PUBLIC SUPPLY COMPANIES AND RAILWAY COMPANIES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| 1 | Nature of work | Stated | Stated | Indefinite | Stated | Stated | N.S. | Stated |
| 2 | Method of control | Stated | Stated | Stated | Stated | Stated | N.S. | Stated |
| 3 | Battery terminal voltage | N.S. | Specified | N.S. | Specified | N.S. | N.S. | N.S. |
| 4 | Total number of cells | Specified | Specified | Specified | Specified | Specified | Specified | Specified |
| 5 | Number of end or regulating cells (if controlled by battery regulator) | None | Specified | None | Specified | N.S. | N.S. | N.S. |
| 6 | Capacity in ampere-hours (expressed as a percentage of the 5-hour rate) — in 10 hrs. | — | — | 120 % | — | — | — | — |
| | " 5 " | — | — | 100 % | — | — | — | — |
| | " 3 " | 86·8 % | — | 87·9 % | — | 86 % | — | — |
| | " 2 " | 73·48 % | 76 % | 76 % | — | 77·3 % | 2 hr. specified | — |
| | " 1 " | 60 % | 66·3 % | 62·1 % | 1 hr. specified | 60 % | — | 1 hr. specified |
| | " 1/4 " | — | — | 26·7 % | — | — | — | — |
| 7 | Final volts per cell — at the 10 hr. rate | — | — | 1·83 | — | — | — | — |
| | " 5 " | — | — | 1·83 | Indefinite | — | — | — |
| | " 3 " | — | — | 1·8 | — | 1·8 | — | — |
| | " 2 " | — | 1·72 | 1·75 | Specified | 1·8 | 1·7 | — |
| | " 1 " | 1·7 | 1·675 | 1·75 | — | 1·8 | — | 1·75 |
| | " 1/4 " | — | — | — | — | — | — | — |
| 8 | Guaranteed watt-hour efficiency — at the 10 hr. rate | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | |
| | " 5 " | | | | | | | |
| | " 3 " | | | | | | | |
| | " 2 " | | | | | | | |
| | " 1 " | | | | | | | |
| | " 1/4 " | | | | | | | |
| 9 | Ampere hour efficiency at all rates | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | 90 % |
| 10 | Maximum volts per cell on charge at normal rate | N.S. | Indefinite | N.S. | N.S. | Specified | N.S. | 2·75 |
| 11 | " at finishing rate | N.S. | Indefinite | N.S. | N.S. | Specified | N.S. | 2·75 |
| 12 | Containers, type | Wood, lead lined | Wood, lead lined | Wood, lead lined | N.S. | Wood, lead lined | Wood, lead lined | Wood, lead lined |
| 13 | " construction | Solid | Specified | Specified | N.S. | Specified | N.S. | Specified |
| 14 | " class of timber | Best pine | Indefinite | Best pitch pine | N.S. | Best yellow pine or American white wood | N.S. | Pine |
| 15 | " finish | Specified | Indefinite | Specified | N.S. | Specified | N.S. | Specified |
| 16 | " space below plates | 8 in. | 6 in. | 30 % of plate length | N.S. | 33 % of plate length | Indefinite | 8 in. |
| 17 | " space above plates | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | 2 in. |
| 18 | " space between end plate and lining | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | Indefinite |
| 19 | " thickness of lining | N.S. | 1/16 in. thick = 4 lb.) | 4 lb. | N.S. | 5 lb. | N.S. | 4 lb. |
| 20 | Electrolyte | Indefinite | N.S. | Indefinite | N.S. | Specified | N.S. | Indefinite |
| 21 | " specific gravity | N.S. | N.S. | N.S. | N.S. | Specified | N.S. | N.S. |
| 22 | " bulk | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 23 | Separation, type | N.S. | N.S. | Wood | Wood | Glass | N.S. | Indefinite |
| 24 | " distance between plates | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |
| 25 | Insulators (cells) | Glass (approved) | Indefinite | N.S. | Indefinite | Glass | N.S. | Glass or porcelain |
| 26 | " (stands) | Porcelain (oil) | Indefinite | Earthenware | Indefinite | Porcelain | N.S. | Glass or porcelain |
| 27 | Connectors inter-cell | Specified | Indefinite | Specified | Indefinite | Specified | Indefinite | Specified |
| 28 | " inter-row | N.S. | Indefinite | Specified | Specified | Specified | Indefinite | Specified |
| 29 | Tests | N.S. | Specified | Specified | Indefinite | Specified | Specified | Indefinite |
| 30 | Current allowed for initial charge | N.S. | N.S. | N.S. | Stated | Indefinite | N.S. | N.S. |

NOTE.—N.S.—Not specified.

THE PAST FEW YEARS, WITH RECOMMENDATIONS FOR FUTURE SPECIFICATIONS.

| | Government Departments | | | Consulting Engineers | | | | Recommendations |
|---|---|---|---|---|---|---|---|---|
| | H | J | K | L | M | N | O | |
| 1 | N.S. | N.S. | Stated | Stated | Stated | Stated | N.S. | This should be specified |
| 2 | N.S. | N.S. | Stated | Stated | Stated | Stated | N.S. | This should be specified |
| 3 | Specified | Specified | N.S. | Specified | Specified | N.S | Specified | This should be specified, allowing for loss of volts between battery and busbars |
| 4 | Specified | Specified | Specified | Specified | Specified | Specified | Specified | This should be based on the specified battery terminal voltage divided by voltage per cell at maximum specified rate of discharge |
| 5 | N.S. | Specified | Indefinite | Specified | Specified | N.S. | N.S. | This should be specified |
| 6 | 9 hour spec.<br>—<br>—<br>—<br>—<br>— | 10 hour spec. (120 % ass.)<br>—<br>94 %<br>—<br>—<br>— | 7 hour spec.<br>—<br>—<br>—<br>—<br>— | —<br>5 hour (100% assumed)<br>4 hr. 95 %<br>3 hr. 85 %<br>2 hr. 72·2 %<br>—<br>— | 123·8 %<br>100 %<br>91·4 %<br>—<br>—<br>— | Indefinite (Frequent momentary discharges at specified rates) | —<br>—<br>3 hr. spec.<br>—<br>—<br>— | One rate at least should be specified, if more than one the other rates should be in the ratio obtained from Fig. 1, i.e. — at the 10 hr. rate 120 %; " 5 " 100 %; " 3 " 86 %; " 2 " 76 %; " 1 " 60 %; " 1/4 " 26·8% |
| 7 | 1·83–9 hr.<br>—<br>—<br>—<br>—<br>— | 1·85<br>—<br>1·8<br>—<br>—<br>— | N.S. | —<br>1·74<br>1·74<br>1·74<br>—<br>— | 1·8<br>1·8<br>1·8<br>—<br>—<br>— | N.S. | —<br>—<br>—<br>1·8<br>—<br>— | If stated, the maximum figures for large batteries (in very large batteries it is better to allow lower values at the higher rates to compensate for loss of volts in lugs) should be:— at the 10 hr. rate 1·83 v.; " 5 " 1·83 v.; " 3 " 1·80 v.; " 2 " 1·75 v.; " 1 " 1·70 v.; " 1/4 " 1·65 v. |
| 8 | N.S. | 75 %<br>—<br>—<br>—<br>—<br>—<br>— | N.S. | —<br>73·0%<br>72·0%<br>71·0%<br>—<br>— | N.S. | N.S. | N.S. | The maximum figures (these should be reduced by 2 % for very large batteries with lower final volts per cell) are:— at the 10 hr. rate 74 %; " 5 " 73 %; " 3 " 71 %; " 2 " 70 %; " 1 " 68 % |
| 9 | N.S | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | This may be taken as 90 % for all rates |
| 10 | 2·75 | 2·75 | N.S. | 2·75 | N.S. | N.S. | N.S. | All Planté cells require 2·75 .. Max. charge volts |
| 11 | N.S. | 2·75 | N.S. | N.S. | N.S. | N.S. | N.S. | Special Planté (Chloride) require 2·6 to 2·7 .. .. .. .. .. " " |
| 12 | Wood, lead lined | Wood, lead lined | Wood, lead lined | Wood, lead lined | Wood, lead lined | N.S. | Wood, lead lined | Wood, lead lined |
| 13 | Specified | Specified | N.S. | N.S. | N.S. | N.S. | Indefinite | Panel or solid walls as preferred. If solid, specify straight or skew dovetailed if preferred |
| 14 | Yellow pine | Pine | N.S. | N.S. | N.S. | N.S. | N.S. | Best pitch pine |
| 15 | Specified | Specified | Specified | N.S. | Indefinite | N.S. | N.S. | Specify number of coats acid-proof paint (three advisable) |
| 16 | 3 in. min. | 3 in. min. | N.S. | Indefinite | 4 in. min. | N.S. | 5 in. min. | Should be 30 % of plate depth with maximum of 9 inches |
| 17 | 1 1/4 in. min. | 1 1/2 in. min. | N.S. | N.S. | N.S. | N.S. | N.S. | Extremes—2 to 3 inches |
| 18 | 1 1/4 in. | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. | This dimension should be 3/4 in. minimum |
| 19 | 4 lb. | 3 lb. | N.S. | N.S. | N.S. | N.S. | N.S. | Chemically pure lead, 3 1/2 or 4 lb. per square foot |
| 20 | Indefinite | Specified | N.S. | Indefinite | Indefinite | N.S. | N.S. | Sulphuric acid, conforming with "Standard" for purity |
| 21 | N.S. | Specified | N.S. | N.S. | N.S. | N.S. | N.S | 1,200 to 1,215 |
| 22 | Indefinite | Drop in specific gravity specified | N.S. | N.S. | N.S. | N.S. | N.S. | Sufficient to enable full output to be obtained with maximum range in specific gravity not exceeding 65° |
| 23 | Glass | Indefinite | Indefinite | N.S. | N.S. | N.S. | Indefinite | Wood, from which all injurious constituents have been removed (best). Glass rod or tube |
| 24 | 1/2 in. | N.S. | N.S. | N.S. | N.S. | N.S. | 1/2 in. min. | 7/16 in. if wood separation, 1/2 in. if open (glass) |
| 25 | Glass or porcelain (oil) | Glass | N.S. | Indefinite | Indefinite (oil) | N.S. | Indefinite (oil) | Solid glass |
| 26 | N.S. | N.S. | Indefinite | Indefinite | Indefinite | N.S. | Indefinite | Porcelain or earthenware |
| 27 | Indefinite | Indefinite | N.S. | Indefinite | Indefinite | N.S. | Specified | Lead, minimum sectional area should be specified |
| 28 | Specified | N.S. | N.S. | Indefinite | Indefinite | N.S. | Specified | Sectional area should be specified |
| 29 | Specified | Specified | Indefinite | N.S. | Indefinite | N.S. | Specified | To be carried out in accordance with I.E.E. standard |
| 30 | Indefinite | Indefinite | Indefinite | N.S. | N.S. | N.S. | N.S. | This should be limited to capacity of battery at 5 hr. rate multiplied by 6 |

NOTE.—N.S. = Not specified.

### (*c*) Tests.

The absence of official standard tests is felt acutely. Merely to discharge a battery for a given number of hours and be satisfied with the result if the final voltage is not below a guaranteed minimum, is crude and non-technical.

Methods employed for testing the efficiency of a battery vary between exactly opposite extremes. Some engineers require the battery to be fully charged, then fully discharged, and again fully charged, the efficiency being calculated from the ratio of the discharge to the re-charge expressed as a watt-hour efficiency. Other engineers require the battery to be fully discharged, then recharged, and again discharged, the efficiency being taken as the ratio of the second discharge to the preceding charge, expressed as a watt-hour percentage. The latter appears to be the more reasonable and practical method with certain provisions.

It is unnecessary to stipulate a standard method of testing for all batteries, but alternative methods might be standardized, and the particular one selected by the engineer should be specified. For instance, one satisfactory method of testing is to discharge the cells at a specified rate to a fixed final difference of potential, then to recharge the cells to an extent equal to 10 per cent more than the number of ampere-hours discharged, and then to repeat the discharge. This will give the effective capacity and efficiency of the cells on the particular cycle and will demonstrate the percentage margin of capacity possessed by the cells over their guaranteed output.

Another method is to discharge the battery at a specific rate of discharge to the guaranteed output, and if the voltage across the battery terminals does not fall below the prescribed limits this will prove that the battery has its guaranteed output. The battery should then be recharged, putting back 10 per cent more ampere-hours than the guaranteed output, and the discharge should be repeated. The battery will have passed its test if on this second discharge the guaranteed output is again obtained without the voltage across the terminals of the battery falling below the prescribed limit. In this second alternative series the guarantees are demonstrated without consideration of the margin in hand.

The author favours this latter method for large batteries because if the battery is to be maintained up to 100 per cent of its guaranteed output, and this output is not to be exceeded at any time, the determination of the margin in capacity does not necessarily form part of the official test.

The diagnosis of a test is not generally appreciated. If a battery is low in capacity it is comparatively easy to locate the cause of the weakness. The hydrometer and cell-testing or switchboard voltmeter will indicate that weakness is present, but will throw no light on the actual cause. The metal cadmium affords a ready means of determining the relative condition of the positive and negative elements. Fig. 4 illustrates the method by which this diagnosis can be applied. The central diagram shows the curve of voltage of a cell during discharge at various rates. The upper diagram shows the curve of potential difference between the positive element and cadmium during discharge The lower diagram represents similarly the potential difference between the negative element and cadmium. It may be noted that the voltage of the cell at any point represents the difference between the two values—potential difference between positive and cadmium and potential difference between negative and cadmium.

### (*d*) Maintenance Agreements

Maintenance agreements in the past have been to a certain extent a cause of irritation and dissatisfaction mainly because there has been no generally accepted standard, and many engineers have regarded the agreement as an insurance to cover all ill-treatment, bad management, and neglect, in addition to the essential object which is the maintenance of the battery in good working order based on a definite ampere-hour capacity and watt-hour efficiency. If a recognized standard maintenance agreement approved by this Institution were available, negotiations would be greatly simplified. When taking out a life-insurance policy no one is permitted to make a selection of the particular insurance company's rules, and to decline to accept the remainder. If the rules are accepted by the great majority, individuals cannot reasonably expect special treatment. As it is, on almost every large battery contract, merely for lack of a common standard, the battery maker's agreement is first pulled to pieces by the engineer and then re-written by the town clerk. Objections and counter objections are bandied to and fro for months, until finally a modified agreement containing the principle of the original, the interpretation of the engineer, and the phraseology of the town clerk, is mutually accepted.

The conditions which lend themselves to form a non-controversial agreement are quite straightforward.

On the contractor's part :—

- The maintenance of a guaranteed ampere-hour capacity and watt-hour efficiency.
- The supply of renewals for all worn-out and defective parts, including all internal fittings, containers, and insulators, but exclusive of stands and connections.
- Repairs of all description to the battery, including cleaning out; scrutiny of records, and periodical inspections.
- Responsibility for instructions to which the battery shall be operated.

On the user's part :—

- The installation and maintenance of suitable recording instruments.
- The employment of reliable testing instruments.
- The free supply of all electrical energy.
- The provision of distilled water.
- The systematic logging of accurate records.
- The renewal of parts broken by the user's staff.
- The observance of the contractor's reasonable instructions.

The appointment of someone qualified to carry out the instructions and generally see that the battery receives proper attention.

The question of the supply of acid is a vexed one. It might appear to come under "renewals," but the amount can be greatly inflated if the cells are much overcharged, or are charged at very high rates, and the contractor is therefore paying for the user's uneconomical operation of the battery. This is an apparent iniquity, but the sum involved is insignificant, compared with the cost of renewing plates, which may be depreciated from the same cause which leads to waste of acid.

### High-tension Batteries.

There has so far been very little experience with batteries working at a line pressure higher than 600 volts in this country. When the Lancashire and Yorkshire Railway decided to employ direct current at 1,200 volts for the electrification of the Manchester–Bury section of their system—a length of 9½ miles—it was necessary to go abroad to study similar schemes. The most instructive—from the battery section—was the electric railway between Stockholm and Saltsjöbaden, a distance of 9½ miles. There the system is a direct-current one at 1,200 volts with overhead conductors, and includes a buffer battery of 650 cells with a rated output of 666 ampere-hours in 1 hour, which represents 800 kilowatts at the 1-hour rate. The battery is employed for the double purpose of levelling up the line load variations in conjunction with a reversible booster, and also as a capacity battery for lighting and power purposes. The dry Swedish climate tends to simplify the question of insulation. The cells are of the ordinary central-station type, the only difference being the doubling of the insulators. The gangways are mounted on high-tension insulators; the walls and columns of the battery room are screened with a lattice-wood structure mounted on insulated brackets; the lamps are hung out of reach; and the battery inspection lamps are fitted in special ebonite carriers and connected by flexible conductors in a "cab-tyre" sheathing. The battery is sub-divided into several sections by means of link connectors. The battery is on two floors, the lower one being treated as an ordinary 600-volt traction battery room, and the upper one being regarded as a high-tension chamber securely locked. Special instructions are issued regarding operations in the high-tension room.

A summary of the instructions may be of interest:—

"The battery attendant must never go alone into the high-tension battery room. He must be equipped with specially well-insulated rubber boots. He must avoid coming into contact with the battery if possible.

"Filling up, replenishing, cleaning of insulators, and such work should, if possible, be carried out only when the battery is not supplying current, and during that time the particular part of the battery should be disconnected. If it is not possible under conditions of service to permit such disconnecting, or if for other reasons it is necessary to touch the battery when in service, the battery attendant must stand on a dry insulated base. If the battery circuit must be broken for repairs, the particular section of the battery must first be absolutely disconnected.

"Insulators on stands, gangways, walls, pillars, etc., must be thoroughly cleaned with water occasionally, and afterwards rubbed dry with a clean cloth."

The dry climate of Sweden is undoubtedly an ally to the railway engineers; in winter the overhead line is at times embedded in snow and ice, but the system continues to work quite smoothly.

The Lancashire and Yorkshire electrification scheme offered more difficult problems. The decision to adopt the third rail 1,200-volt direct-current system, coupled with the prevalent humidity of the Lancashire climate, led one to foresee possible trouble through leakage to earth However, by careful attention to the question of battery insulation, and taking every precaution to prevent the possibility of anyone making an earth connection while in the battery room, the risks have been minimized if not entirely eliminated. There are two battery substations, one at Victoria Station, Manchester, and the other at Radcliffe.

Each battery consists of 580 T.P.W. 5/8 Plantide cells supplied by the Chloride Electrical Storage Company, Ltd. Each battery is divided into a low-tension and a high-tension section, i.e. equivalent to two batteries placed in series. The low-tension section is constructed as an ordinary 600-volt traction battery, whilst the high-tension section is dealt with on very similar lines to those described in the Swedish system. The working of the batteries is normally controlled by Entz automatic reversible boosters. An interesting modification of the usual system of tapping a series of three-wire 100-volt sections off the battery to provide the booster excitation current uniformly by means of a selector panel has been adopted. The first 50 cells at the "earth" end of the battery permanently supply the current for excitation, and also for station pilot-lights and for the various relays in the switchgear. No selector leads therefore are carried to the high-tension portion of the battery. The 50 cells are charged from a small motor-generator which on occasions may be employed to charge individual cells.

Summarizing this particular section of large batteries for power purposes it may be said with full confidence that 1,200-volt direct-current batteries are almost as simple to operate as 600-volt sets, and the only special points to which particular attention is essential are the proper insulation of the battery and the provision of safeguards to prevent the operators from sustaining shocks which might prove fatal.

### Central Station Batteries.

A description of most of the notably large batteries in this country has been given in the electrical Press, or in papers read before the Institution. In all the batteries the positive plates are built on the Planté principle, either as one lead casting or as a series of lead rosettes inserted in a cast grid of antimonial lead.

The battery at the Eagle-street substation of the Metropolitan Electric Supply Company may be regarded as the acme to date of the special Planté type, while

the batteries at Manchester, Bradford, Birmingham, and Wolverhampton represent the latest practice in true Planté batteries. The relative sizes and outputs of large central station batteries in this country are given in the tables issued annually with the *Electrician* and the "Electrical Trades Directory," so the data has not been re-compiled.

In the Eagle-street battery one finds the problem satisfactorily met of obtaining a huge battery suitable for heavy daily demand on peak work, yet confined to what might appear a disproportionately small floor space. Each positive plate measures only $16\frac{1}{8}$ inches in width, but its depth is $46\frac{3}{8}$ inches, or of a proportion of nearly 3 to 1. No inequality in the distribution of current has been perceived on charge or discharge. Not a single instance of buckling or distortion of the plates has occurred in two years' working, and it may be assumed that plates even 25 per cent deeper than those at Eagle-street would work equally satisfactorily and be strong enough to carry their own weight. The weight of one positive plate is 90 lb., and that of one negative is 41 lb. There are 26 positive plates and 27 negative plates in each cell. The battery comprises 110 "Chloride" cells, C.V.W 26 type, but the substation is designed with the intention of duplicating the battery at some future date.

The external dimensions of one cell are $21\frac{3}{4}$ in. $\times 49\frac{1}{8}$ in. $\times 65\frac{7}{8}$ in., the height overall being $68\frac{3}{4}$ in. Each cell weighs 6,080 lb., of which 3,452 lb. represents the weight of the plates and 1,700 lb. the weight of the acid. The total weight of the battery—about 300 tons—is carried on 2,640 solid glass insulators $3\frac{1}{2}$ inches in diameter. The whole battery, including the stands or wood stillage, is supported on 480 strong glazed earthenware insulators, each having an actual bearing surface of 17·27 square inches. The concentrated weight works out at 90 lb. per square inch. The cells are contained in lead-lined wood boxes, and the Metropolitan Electric Supply Company have allowed an interesting experiment to be carried out to determine the respective durability and other merits of panel and flush boxes under identical working conditions. For this purpose some of the boxes are of the panel type, and the remainder are of the flush pattern with skew-dovetailed joints. The figures as to capacity at various rates are as follows:—

12,000 ampere-hours at the 10-hour rate to 1·8 volts per cell.

10,000 ampere-hours at the 5-hour rate to 1·78 volts per cell.

7,500 ampere-hours at the 2-hour rate to 1·7 volts per cell.

6,000 ampere-hours at the 1-hour rate to 1·65 volts per cell.

The battery is also capable of discharging at 8,000 amperes for 35 minutes. or 15,000 amperes momentarily. The normal charging rate is 1,400 amperes, and the maximum continuous charging rate 2,570 amperes.

### Stand-by Batteries.

It is noteworthy that whereas large and even enormous batteries solely for stand-by purposes have been and continue to be installed and form the bulk of central-station battery storage in the United States, no large purely stand-by battery has yet been installed in this country. American engineers claim that developments are bound in time to lead engineers here to adopt the same line of policy as theirs, as the smaller stations become absorbed and bulk supply becomes more universal. In intelligent anticipation of such an epoch a review of the modifications from standard stationary battery design called for in stand-by batteries may be useful.

It is an axiom that a Planté plate must be given fairly constant work or its condition will deteriorate. The Faure or pasted plate on the other hand will endure long periods of idleness without suffering any permanent after-effects. By a fortunate coincidence it is possible to obtain far more capacity for unit weight and cubic contents from a Faure cell than from a Planté cell. A cell of the Faure type is therefore eminently suitable for stand-by .purposes. Its durability is inferior to that of Planté cells, but as it is possible to obtain 300 to 500 discharges from one set of plates this should amply cover emergency requirements for a period of 10 years.

Mr. A. M. Taylor's paper entitled "Battery Economics and Battery Discharge Arrangements" read before the Institution in 1911 * referred to the "Exide" accumulator manufactured for stand-by batteries by the Electric Storage Battery Company of Philadelphia. This company has installed 43 "Exide" stand-by batteries for central stations during the past nine years. The "Exide" negative plate is not unknown in central station work in this country, as one set operated in daily use for $8\frac{1}{2}$ years (1905 to 1913) in the large battery at the Fisher-street substation of the Metropolitan Electric Supply Company. For extensive practical results we must, however, still refer to the United States.

The grid of the "Exide" positive and negative plates is a casting of antimonial lead, consisting of a series of vertical ribs connected by short horizontal bars. The latter are flush with the plate surface, but extend only part way through the plate, and are staggered on opposite sides. Thus the active material is in the form of continuous vertical strips or slabs extending from the top of the plate to the bottom between the vertical ribs, and locked in place by the horizontal bars. A plate built on this principle measuring 15 in. wide $\times 31$ in. high and 7/32 in. thick weighs approximately 25 lb. and has a rating of 166 amperes for one hour, rather more than twice the one-hour rating for 20 minutes, and over three times the one-hour rating for 10 minutes.

An "Exide" cell with a capacity of 9,000 amperes for one hour measures approximately 5 feet in length, 21 inches wide, and 5 feet high.

The largest stand-by battery installed in the United States up to the time the data was collected for this paper was at Detroit (Mich.). The maximum peak load during the winter of 1915–1916 occurred at 5 p.m. on the 17th December, 1915, and amounted to 55,700 amperes at about 134 volts on each side of the three-

* *Journal I.E.E.*, 1911, vol. 47, p. 393.

wire system. The combined capacity of the four batteries installed will carry this load for 14 minutes. One battery alone consists of 150 "Exide" cells, type H. 169, installed in 1915, with a capacity of 25,200 amperes at 110 volts for one hour, or 80,000 amperes for 10 minutes.

Normally a stand-by battery floats on the supply system, regulating momentary fluctuations and in readiness for peak and emergency discharging, the adjustment being such that during the floating period the total amount of charge compensates for the discharge. The battery should be floated so that the pressure per cell in circuit will be between 2·10 and 2·14 volts, averaging as near as practicable 2·12 volts. Adjustment is made by cutting in or out end cells. The following table indicates the proper number of cells upon which to float to give the above average cell voltage for different busbar voltages.

| Voltage of Busbar | Number of Cells in Circuit |
|---|---|
| 117·7 to 119·7 | 56 |
| 119·7 to 121·9 | 57 |
| 121·9 to 124·0 | 58 |
| 124·0 to 126·1 | 59 |
| 126·1 to 128·2 | 60 |
| 128·2 to 130·2 | 61 |

### Stand-by Batteries Applied to Alternating-current Stations.

The installation of a storage battery for stand-by service on an alternating-current circuit presents no insurmountable engineering difficulties, and an interesting example of such an application is found at the Newton substation of the Edison Electric Illuminating Company of Boston (Mass.). Power is received at 13,800 volts, three-phase, 60 periods, over duplicate transmission lines, a distance of 12 miles. The substation supplies three classes of service, viz.

(1) The local commercial load of lighting and power supplied to the distribution feeders at 2,300/4,000 volts, four-wire, three-phase.
(2) Series arc lamps for street lighting.
(3) Direct current at 575 volts for operating the suburban electric railway in the district.

The original arrangement of the apparatus in this substation is shown in Fig. 5 in full lines, while the apparatus added in connection with the battery installation is shown in dotted lines. The diagram is conventional and shows only one phase of the three-phase circuits, and one side of the direct-current railway circuit. Duplicate high-tension busbars are provided, and duplicate oil switches for each incoming and outgoing

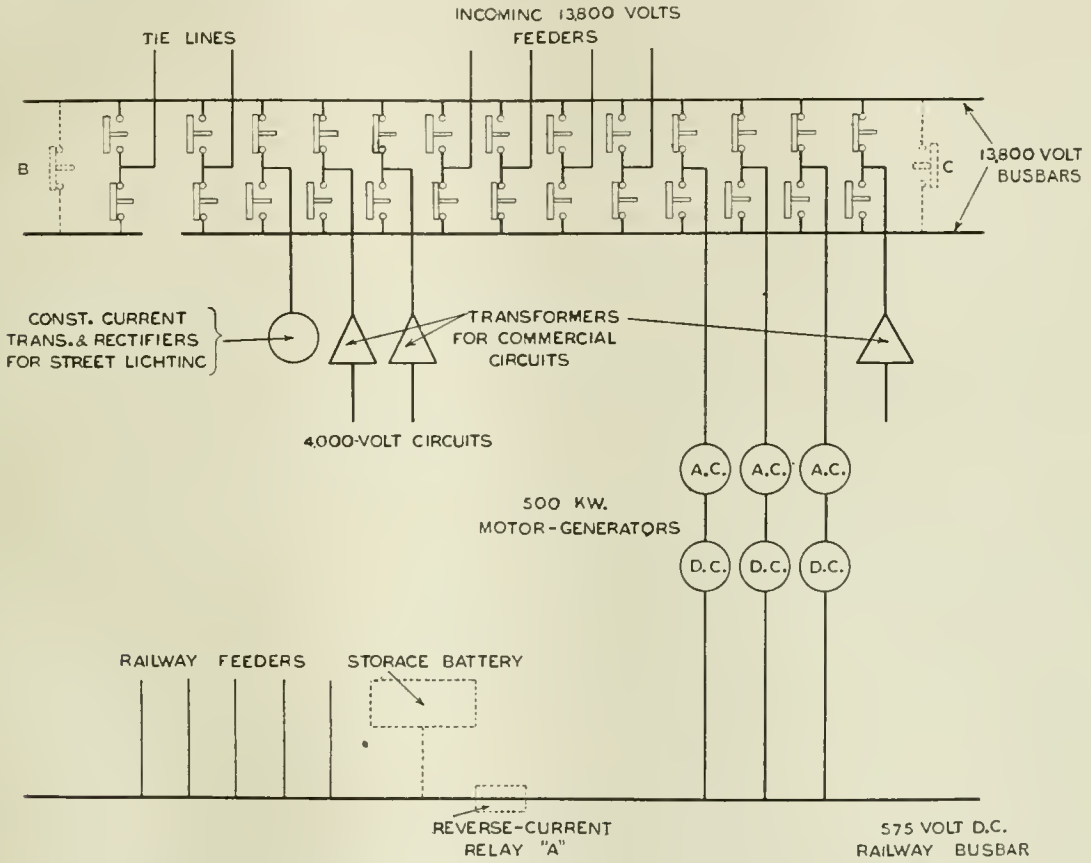


FIG. 5.—Stand-by battery applied to alternating-current system, Newton (Mass., U.S.A.).

circuit permit each circuit to be connected at will to either set of busbars. Step-down transformers furnish the 2,300/4,000-volt current for the local commercial load. Constant-current "tub" transformers with mercury-arc rectifiers are used for the street lighting, and three 50-kw. motor-generator sets furnish the 575-volt direct current to the railway busbars. Each of these units consists of a 13,800-volt synchronous motor direct-connected to a 575-volt interpole direct-current generator.

An "Exide" battery consisting of 344 cells, type H. 31, having a capacity of 2,250 amperes for one hour, or 4,650 amperes for 20 minutes, has been installed. During normal operation the battery floats directly across the railway busbars, which are maintained at a substantially constant voltage, so that the battery is doing no work. In case of any trouble on the high-tension distribution system of sufficient magnitude, the battery takes up all of the railway load and feeds back through motor-generator sets into the local alternating-current circuit, but not into the entire high-tension distribution system.

In order to ensure constant voltage during emergency discharges, the battery is provided with motor-operated end-cell switches automatically controlled by a contact-making voltmeter connected across the battery terminals.

### Working Results.

The large batteries at Manchester, Bradford, Birmingham, Wolverhampton, and the substations of the Metropolitan Electric Supply Company, to mention only a few of the large batteries in this country, all show results which prove that the practicability of very large batteries is assured. To avoid what might appear invidious comparisons, the author has left any definite statements about the degree of success obtained to be given at the option of the engineers concerned.

One problem connected with the operation of large batteries for power purposes is the inevitable overhaul which is sometimes apparently unforeseen by engineers when drawing up their specifications. Conditions of working involve various methods for dealing with repairs and renewals. The cleanest and most satisfactory way is to put the battery out of commission entirely for the period of overhaul, stipulating that by concentrating a large supply of labour and a complete consignment of material the contractor shall reduce the period to a reasonable maximum undertaken at a season when the loss of the battery would be least felt. If conditions of service demand continuity of supply from the battery, as for instance in the case of large batteries used as load regulators on power installations — railways, for example—then the requisite facilities for dealing with single cells or small batches of cells must be provided in the shape of charging boosters or auxiliary charging generators.

It is on the occasion of an overhaul that a carefully designed and well-equipped battery room is most appreciated. The importance of keeping the plates thoroughly isolated from the lead linings is also realized when a battery has to be cleaned out, for if the negatives are at all in contact with the linings the sediment becomes a mass of sulphated spongy lead very much like concrete in consistency.

### Control of Large Batteries.

The principles on which large batteries are controlled have not changed materially during recent years, but the policy adopted in practice has undergone an appreciable change. It remains a recognized fact that without some means of variable voltage regulation the amount of useful work to be obtained from the battery is very limited. To effect this regulation the choice lies between end-cell switches and boosters. Continental practice is solidly in favour of end-cell regulation. Until five years ago American practice favoured automatic boosters for almost all purposes, but now the trend in the United States is to employ motor-driven end-cell switches where the battery is used for lighting service (on peak work or for stand-by service) and automatic reversible boosters only where the control is required for rapid momentary fluctuations. Very few reversible boosters are now being installed in large power plants in the States, the explanation given being that this regulation of momentary fluctuations is falling into disuse in connection with large power systems, due in part at least to the combination of small systems into large ones, whereby the loads formerly carried by a number of power plants have been concentrated on a few large power houses, and the momentary fluctuations have thus become a smaller percentage of the total and therefore of minor importance.

Batteries are still used with automatic reversible boosters, or so-called constant-current boosters for regulating the momentary fluctuations in American plants which would appear big in this country.

Colonial practice, as might be expected, is divided between the two forms of battery control, the result doubtless of the markets being closely "nursed" by Continental and American manufacturers, whereas the undertakings are controlled largely by British engineers.

In this country, where so many types of boosters have been invented and exploited, it is natural to find that boosters have so far formed the predominant method of controlling large batteries, despite the strong aversion on the part of some British manufacturers to build these special machines. There is undoubtedly much to be said in favour of booster control for even the largest batteries which have so far been installed in this country. The Manchester battery is controlled by an automatic reversible booster, though this is almost invariably run as a hand reversible set. The Wolverhampton battery is worked in series with a hand reversible booster. It was proposed to run the Bradford battery with end-cell control, but the cost of the switches and copper led those concerned to decide eventually on hand reversible boosters. At Eagle-street the battery is controlled by hand reversible boosters.

All the above are large batteries for lighting and power purposes.

Large power batteries used essentially for load regulation, such as on the Lancashire and Yorkshire Railway, the London and North-Western Railway, and the Great Western Railway, are all operated by means of automatic reversible boosters.

Sufficient instances have been quoted to show the lines followed up to the present. It is possible—in fact, probable—that some engineers if able to make a fresh start with their battery scheme would reverse their original decision as to method of control. It has to be remembered that a booster is required for charging the battery in every instance, and it would therefore appear economical at first sight to make use of the booster on discharge also: but this entails a very considerable increase in the size of the booster if it is to be capable of carrying the battery overload ratings and also supply the necessary voltage to allow for the falling characteristic of the battery pressure on discharge at high rates. There is consequently an increase in the energy consumed in running the booster set.

### Boosters.

The paper read by Mr. R. Rankin before this Institution in 1911 * may still be regarded as a compreprehensive up-to-date review of all modern types of boosters.

The Entz booster still holds a strong claim for superiority in all classes of heavy load regulation, notably

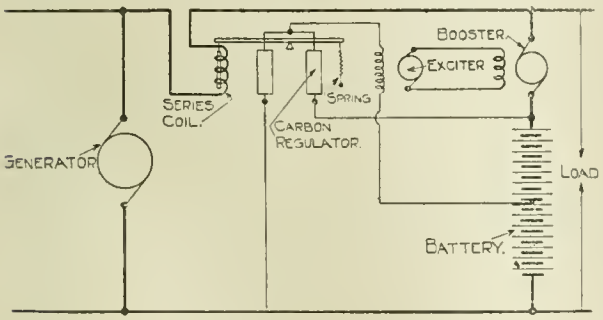


Fig. 6.—Diagram of connections for Entz control.

on railways, and within the past three years numerous Entz boosters have been installed on railway systems at home and abroad. Fig. 6 shows diagrammatically the connections for the Entz booster control of storage batteries, and although the connections look very simple they comprise all that are requisite and employed.

The principle on which the Entz booster operates is now so widely known that it is perhaps unnecessary to dwell on it, but in explanation of Fig. 6 it may be pointed out that the battery is connected across the feeder busbars and in series with the generator armature of a motor-generator or booster set. The booster has its fields energized by an exciter, the field of this exciter being varied in a positive or negative direction by current from carbon piles connected to either end of the battery. These piles are depressed through the action of a coil in the main generator circuit opposed by a spring, as indicated in the diagram. When the load is at the average, the coil and spring neutralize each other's action and the carbon piles have an equal amount of current in them. When the load fluctuates above the average, tending to call for more current from the generator, this increase of current in the coil overpowers the spring and the carbons on one side are compressed, energizing the booster field in a direction to add to the voltage of the battery, thus causing it to discharge. On this discharge the battery voltage drops due to its internal resistance and polarization, and the carbon regulator, being extremely sensitive, so adjusts the booster voltage that the battery discharge plus the average load equals the outside load. On fluctuations below the average the load on the generator tends to drop and the spring overcomes the coil, the battery receiving a charge equal to the difference between the average and the outside load. The Entz system has been applied successfully to alternating-current regulation as well as on direct-current service.

* *Journal I.E.E.*, 1912, vol. 48, p. 283.

### End Cell Switches.

The cell switch is a vital part of the stand-by battery installation. Its importance can hardly be overestimated. Unless this part of the installation is absolutely reliable and capable of handling the battery output under all conditions the value of the battery as an emergency reserve is seriously impaired. In this country engineers have been accustomed to regard German manufacturers as having a monopoly of large cell switches, but if this has been true in the past, it is equally true that it is quite unnecessary to go to Germany now for a reliable article. The Electric Storage Battery Company of Philadelphia have supplied about 700 motor-driven end-cell switches in one or other of their three standard sizes, which have continuous rated capacities respectively of 3,000, 5,000, and 10,000 amperes. In this country manufacturers have not devoted much attention to the design of very large switches until comparatively recently, but one firm at least, Messrs. Bertram Thomas, has tackled the problem successfully. In view of the importance, a brief description of the switches of the two firms mentioned may be of interest.

Each of the American 5,000- and 10,000-ampere cell switches has two horizontal rails of rectangular section and two rows of contact points arranged alternately at the corners of an imaginary square, four travelling brushes occupying the sides of the square. The brushes are mounted on, and suitably insulated from, a travelling carriage driven by a horizontal driving screw which runs the entire length of the switch. The driving screw is geared at one end to a motor, which is provided with semi-automatic distant control, so that the switchboard operator can start the brush in either direction from any point and bring it into full contact with any other point, but cannot stop it between two adjacent points. The 10,000-ampere cell switch has been operated repeatedly when connected to the end cells of the largest stand-by battery installed, the brush being run many times in succession from one end of the switch to the other, either with or without load, without any appreciable sparking and without causing any burning or pitting of the contact surfaces of the brushes. When it is considered that the short-circuit current of one of these large cells may exceed 150,000 amperes, the magnitude of the problem may be partially realized

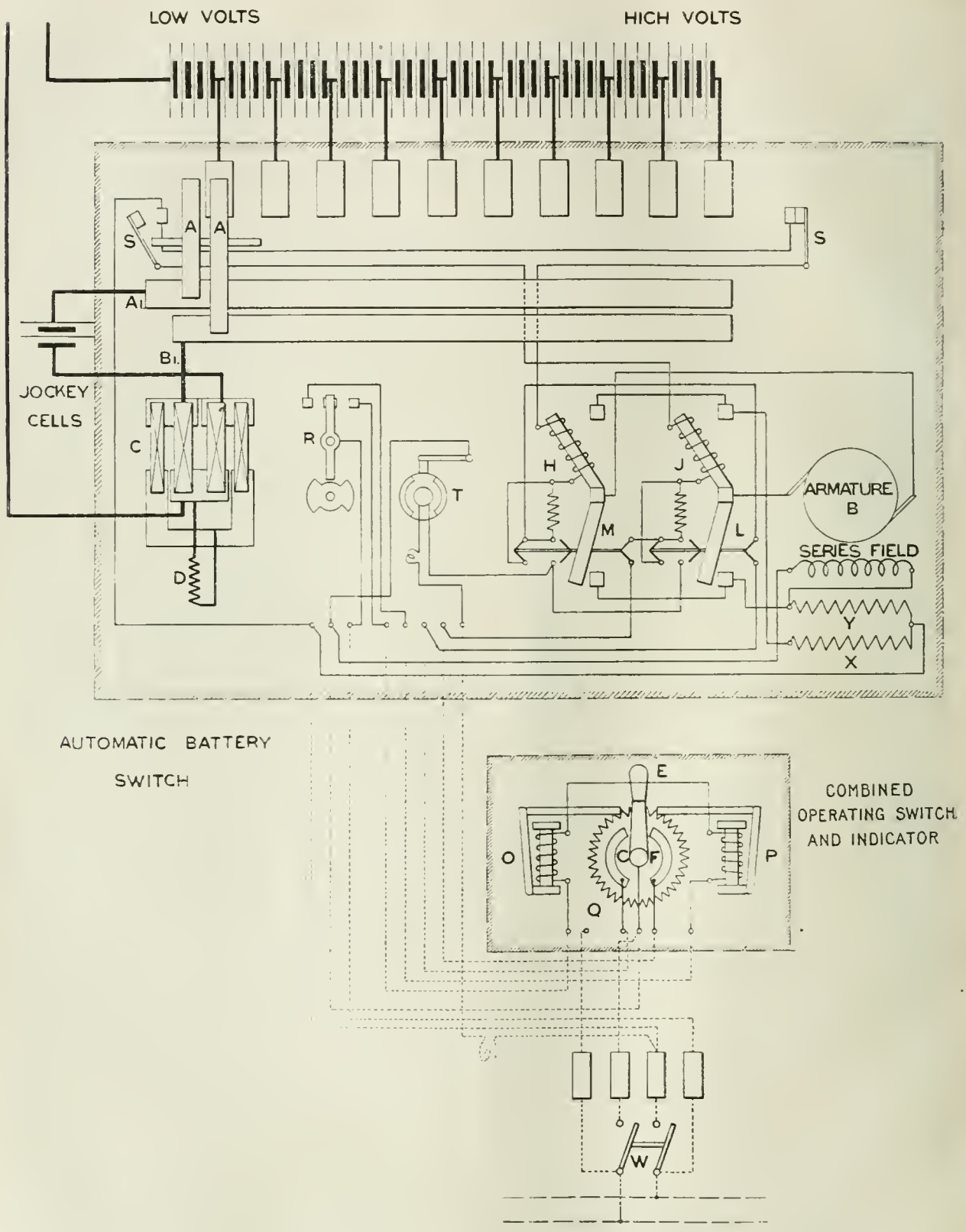


FIG. 7.—End-cell switch connections (Bertram Thomas pattern).

The continuous rating of the end-cell switches should correspond to the one-hour rating of the battery. The overload capacity of the switches is then sufficient to handle any output which the battery can furnish. Thus if the battery is rated at 10,000 amperes for one hour or 40,000 amperes for six minutes, the 10,000-ampere cell switch will carry the battery output of 40,000 amperes for six minutes, and the travelling brushes can be moved from point to point under this 40,000-ampere load without injurious sparking, even where three or four cells are connected between adjacent points. It is usual practice to install two or even three cell switches on each side of a three-wire battery, each switch in the case of two, or two in parallel in the case of three, being sufficient to carry the entire battery output, thus providing a spare switch on each side. This also permits floating the battery on a high and a low voltage busbar at the same time.

The British-made end-cell switch as supplied by Messrs. Bertram Thomas is a remote-controlled regulator fitted with a lead-saving device shown diagrammatically in Fig. 7. The switch arms A A are moved simultaneously by the motor B, which is started and stopped by a combined switch and indicator. By moving the switch handle E on to one of the two contacts F and G the coils of one of the two small contactors are energized, and this operates one of the direction switches L and M, thus energizing the motor in the necessary direction to drive the battery switch to cut cells in or out. During the movement of the switch arms A A the four circuit breakers C are operated by cams, so that during the travel from one contact to the next the auxiliary or jockey cells are brought into operation, as also the pilot resistance D which is introduced to prevent short-circuiting of cells.

All making and breaking of circuit and changing from one cell to the next takes place on the four circuit breakers C. The two racking contactors O and P on the combined switch and indicator operate on a ratchet wheel Q. The coils of these two contactors are energized by the auxiliary switch R, which is in turn operated by the battery regulator, and makes contact in one or the other direction with each complete step traversed by the battery regulator. On each occasion the switch R makes contact it energizes one of the contactors O or P, and this in turn racks the centre wheel of the indicator round which carries the contacts F and G. The battery switch continues to travel and the contactor repeats the racking motion until the gap in the contacts comes opposite the handle E, at which point the battery regulator stops. When once an operation has been initiated by the operating switch E, the direction switch L or M, as the case may be, is held closed until the completion of a step by means of the auxiliary switch marked T, which is mounted on the regulator shaft, and energizes the contactor of the direction switch independently of the operation switch as long as the regulator is between two steps.

### The Future Aspect as Regards Storage Batteries.

The author will not attempt to forecast the future with regard to the installation of large batteries, but the paper may be deemed incomplete if no reference is made to the matter. The effect of war conditions, the increase in the size of power stations with their increased area and improved diversity factor, and the tendency to insist on three-phase alternating-current supply for power purposes, are all bound to influence future policy. It may be of interest to note that the general trend of practice in the United States in the application of large storage batteries for power purposes is to limit these battery installations to strictly stand-by service. The reason for this appears to be found in the fact that absolnte assurance of continuity of service in the congested centres of large cities is becoming of greater and greater importance, whereas the efforts of public service corporations to improve their load factors by making attractive rates for off-peak load, as well as the improvements effected in modern machinery in the matter of overload capacity for short periods of time, tend to render the use of batteries on a daily peak of considerably less importance. It appears to be the general experience in the United States that the average load on central stations is increasing faster than the peak load, so that the latter falls more nearly within the overload capacity of the machinery necessary for carrying the average load on continuous ratings.

Many of the batteries originally installed in American stations for daily peak work are now merely held in reserve for emergency service. This has led in some cases to the battery being discarded when the existing set of plates has worn out, but in most other cases the batteries have been renewed with plates of stand-by pattern; in fact this practice has become quite general in large central stations batteries for lighting service.

It should not be assumed from this statement that the use of batteries is decreasing in the United States, but the purposes to which the batteries are put have changed very considerably in the course of the last 10 years. For instance, one American battery company has a record of 300 of its batteries now in service in connection with central stations for electric lighting with a total capacity of 163,000 kilowatts at the one-hour rate, and of these 300 batteries more than 50 are large stand-by batteries. To avoid further misapprehensions regarding these facts it should be pointed out that the same company has some hundreds of large batteries in connection with electric railway systems, steel mills, and other power plants. This note is added because the figures differentiate between lighting service batteries and power batteries.

## Discussion before The Institution, 25 April, 1918.

**Mr. C. H. Wordingham**: I should like to say a few words in regard to standardization, because it is a matter in which I have always felt a very keen interest, and it would be helpful, I think, if speakers would touch upon that among other points. It seems to me that there should be no difficulty whatever in the British Engineering Standards Association at once taking up the standardization of items (*b*) and (*c*) referred to on page 496 of the paper—that is to say, specifications and tests. Those two things are pre-eminently matters which could best be dealt with, and could probably be dealt with speedily, by the Association, and as the author says, it is desirable that the matter should be taken up by representative bodies. On the question of design of cells I am not so sure. The Engineering Standards Association invariably does its utmost to keep away from questions of design, preferring to specify results and only those dimensions that are necessary for interchangeability. However, that matter can be considered. With regard to maintenance agreements, that seems to me to be quite outside the scope of the Association, but it is essentially a matter in which the Institution could lend a helping hand, and I think we might very well consider the formation of a Committee to deal with that question. It is on all fours with the Conditions of Contract which were drawn up by the Institution some years ago and which have proved, I think, very useful to manufacturers and to users. The author mentions the importance of paint for the cells. That question, I think, might very well be referred to the Insulating Materials Research Committee for consideration. It will work in very well with the question of varnishes, which is being very seriously considered in relation to the application of varnishes to insulating cloths and so on. One point which the author emphasizes is the question of revision of specifications. It should be generally known that all the British Standard Specifications come up for revision every year. It does not follow, of course, that any change is made, but they are all brought up automatically for reconsideration every year, and if any necessity can be shown for alterations, those alterations are taken in hand.

**Captain A. M. Taylor**: I am particularly interested in the author's remarks relative to stand-by batteries. Opinions may be somewhat divided as to whether it would be better to have a battery which would give, say, 80,000 amperes for 10 minutes or one to give 25,000 amperes for one hour; but if one and the same battery would give either, it would be an asset of great value. It would be very interesting to know what is the relative capital cost of such cells, which I believe are made out of thin plates, compared with cells intended for discharges up to 3 hours, or more, regularly. It might not be out of place to raise again the question as to whether a battery is really a profitable investment for a supply undertaking—not, of course, at the present price of lead, but at pre-war prices. To begin with, it is essential that station engineers should agree as to the actual cost of the current put into the cells, if put in at non-peak hours. I have maintained all along that this particular charging current only costs the station about 0·15d. per unit (see the table published in the *Electrician*, 4 December, 1907, giving an analysis of costs, on which this and other charges are based). If this be granted, and if we take the fixed charges—up to the substation low-tension busbars—for one of the largest municipal generating stations at £5 8s. per kilowatt of maximum demand per annum, stand-by coal at 10s. per kilowatt of maximum demand per annum, and running charges at 0·15d. per unit, we obtain the following:—

(A) Load factor 20 % : 1,752 units @ 0·959d. per unit;
(B) ,, ,, 30 % : 2,660 units @ 0·684d. per unit;

in each case with steam alone. Now consider the extra expense to the steam side of the station caused by the charging of the cells, neglecting for the moment the reduction in steam plant effected, for a given maximum demand, 25 per cent of the load-curve area or 438 units being put into the cells in the case of (A), and 33 per cent or 886 units in the case of (B), 50 per cent total loss, including boosters, being allowed on these quantities in each case. We then get the following:—

(A) 20 % load factor:—

1,752 units @ 0·959d. } = 0·98d. average, per effective unit.
219 (waste) @ 0·15d. }

(B) 30 % load factor:—

2,660 units @ 0·684d. } = 0·707d. average, per effective unit.
443 (waste) @ 0·15d. }

Next, take the cost (including all charges) of the useful units actually obtained out of the cells (taking fixed charges for cells as in Fig. 1 of the article in the *Electrician* of 4 December, 1907) delivered, as in the case of steam, at substation busbars (where battery would be placed); and we have:—

(A) 20 % load factor:—1·2-hour rate. Fixed charge = £1 12s. per kw. per annum.

438 units @ 0·88d. + 0·15d. } = 1·03d.
219 (waste) @ 0·15d. }

Cost per "effective" unit = 1·105d. as against steam @ 0·959d.

(B) 30 % load factor:—2·43-hour rate. Fixed charge = £2 per kw. per annum.

886 units @ 0·54d. + 0·15d. } = 0·92d.
443 (waste) @ 0·15d. }

Cost per "effective" unit = 0·765d., as against steam @ 0·684d.

The difference between the two costs would disappear if a rather smaller steam station had been considered and the saving in capacity of the steam plant has yet to be credited to the battery.

**Mr. F. Crawter:** I am glad to think that the old idea of tiled floors for battery rooms is going out. It was always difficult to prevent the acid from getting underneath the tiles and in a very short time forming large blobs all over the floor, which when trodden on gave under one's feet. I think that an ordinary concrete floor, cement rendered, or possibly rendered with asphalt, is as good as any. The trouble with asphalt, of course, is that however carefully we may draw the specification, we are never quite certain until a job is finished what sort of asphalt we shall get. The difficulty is to get asphalt which will not soften, and which will bear a reasonable weight, without forming dents. As the author shows in Fig. 3, it is practically universal practice now with large batteries to arrange for the weight to be taken directly on the building itself and not merely on the floor. When dealing with the question of temperature the author does not dwell on the fact, which of course most people know, that temperature affects the specific gravity of the acid in the battery; and although this is really of not much importance with batteries in this country, it has some direct bearing on batteries installed abroad, where the temperature of the battery room may materially affect the specific gravity and where, if this point is not borne in mind, damage is likely to accrue to the battery simply because the attendant, ignoring the temperature, tries to get the gravity up to the standard. The variation is practically 1 degree for every 3 degrees F. above or below 60° F. The author mentions on page 496 the importance of spacing double rows of cells so as to be able to get at the sides of the boxes. This is really important because the cost of the boxes is quite an appreciable percentage of the total cost; and by simply arranging the cells so as to get a paint brush in between them the life of the boxes is very considerably prolonged. The author also deals with the question of aluminium for connections, and it is somewhat surprising that the use of this metal has not become more general. I know of instances where aluminium battery connections have been in use for 4 or 5 years without any protection whatever; simply the bare aluminium in the form of rod run directly from the cells to the switchboard without any joints. The drawback, if it can be called a drawback, is that one cannot make quite such a neat job with aluminium rod as one can with copper; but the experience I have had of aluminium during the last 4 or 5 years shows that it forms quite a good metal for battery connections. The author deals on page 504 with the battery at Eagle-street substation and, as it is of interest, I should like to draw attention to one or two points in its construction. The depth of the plates is $1\frac{1}{2}$ inches short of 4 ft. The weight of the cells is taken through the pot insulators on to a ridge which forms part of the floor itself. That is to say, in building the room the bridge is made of metalline bricks laid directly on the concrete, and the asphalt is brought up round the bricks for $1\frac{1}{2}$ inches and hot-ironed against their edges. The result is that there is no possibility of any acid spilt on the floor getting down to the concrete forming the building itself. In that battery, as the author points out, each individual cell weighs just under 3 tons. The lantern slide gives some idea of the size of the stand-by batteries used in America. That particular battery is capable of giving 80,000 amperes for 10 minutes. The last two slides which I should like to show illustrate the effect of a hand reversible booster in maintaining a constant load on the generators.

**Mr. H. Brazil:** I quite agree with the last speaker regarding the unsuitability of tiles for floors, because if the acid gets underneath, the tiles will become loose. We have had experience with two kinds of floors. One is asphalt, and that, though a very good insulator, is undoubtedly not satisfactory because it is too soft. The trouble is that the cells sink in but not to the same extent, with the result that one cell cants one way, and another in a different direction; and as the plates are supported by a glass sheet and the plates in one cell are rigidly fixed to those in the next, the strain on them is very considerable. The most satisfactory solution we have found is to use a floor of powdered glass and cement. In the first instance we coated this with Stockholm tar, but the tar very soon wore off and was never renewed. That is about 15 years ago, and the floors are still doing very well indeed except for a slight amount of dust. With regard to the effect of temperature on the cells, batteries are often placed either alongside or above engine-rooms or machine-rooms, so that the battery-room temperature is often much higher than the outside temperature. I have known a case of a battery-room temperature of 85° F. This high temperature has advantages, as the author points out, in that the capacity of the battery is increased very considerably, the voltage also being higher, but it also has disadvantages, as I can vouch for from experience. One battery within my knowledge, where it was impossible to prevent the temperature being high, gave a good deal more trouble from chemical action than the others. With regard to the use of copper rods between the cells, bridging across from one row to another, we have found this to be exceedingly satisfactory and we have had none of the trouble, mentioned by the author, of acids attacking the metal. Undoubtedly, on the whole, wooden separators are good, and particularly in a new battery where the plates are not buckled. But if a battery has been used a considerable time and buckling starts, the force exerted is so great that the wooden separators, which are not mechanically strong, cannot stand it and the plates come together; also one cannot examine the plates with a lamp in the case of a battery with wooden boards, as there is no room between the plates. This is a disadvantage, and a very sensitive galvanometer has to be employed in order to find faults, but these sensitive galvanometers are not exactly things one would care to put into the hands of an ordinary battery attendant. With regard to tests, on page 502 the author states that "to discharge a battery for a given number of hours and be satisfied with the result if the final voltage is not below a guaranteed minimum, is crude and non-technical." I think he is rather harsh there. We have taken a very large number of tests within the last 15 years, and I think if care is taken in making allowance for the few cells that drop out, the test gives a very reliable result and, further, gives us what we really

want in practice. My experience of maintenance agreements is that they are very satisfactory if a reliable firm has installed the battery and if the conditions laid down by the manufacturers are observed, such as the use of distilled water, the periodical testing of the voltage of each cell, and over-charging once a week. I think it is a very serious matter for a central station engineer to have the responsibility of maintaining and repairing his batteries. This is really a technical business of which he probably has had little or no experience, and I therefore think that maintenance agreements should be encouraged in every way. As to the size of the battery, the author talks of large batteries. The question is whether he means by that large individual cells or batteries of large kilowatt capacity. In our case we can supply 25,000 amperes at 200 volts, say 5,000 kw., from batteries alone for 1½ hours and 7,000 kw. for a shorter time. This brings me to the question of batteries having a 10-minute discharge. It has never appealed to me that a battery should be specified to give a discharge for 10 minutes, because in the event of a breakdown serious enough to warrant discharging at this rate it is not likely that one would be able to put things right in 10 minutes. One and a half hours may be too long, but I think 10 minutes is certainly too short. With regard to end cells and boosters, I agree with the author that, as we are compelled to have a booster for charging, it is good economy to use this also for discharging. The objection he raises, that this entails an increase in the size of the booster and extra energy in running the booster set, is almost entirely done away with if the type of booster I described in the discussion on "Voltage Regulation of Rotary Converters,"* is employed. The booster in this case is mounted direct on an extension of the shaft of a rotary converter, and thus does away with most of the loss incidental to motor-driven boosters.

**Mr. E. S. New**: As secretary of the Accumulator Makers' Section of the B.E.A.M.A. I have tried, but not very successfully,to get certain points standardized. I think all battery makers would welcome a standard specification, but it is very important that if any attempt be made to obtain a standard specification the Government departments, who are the worst sinners in respect of drawing up impossible specifications, should join in any such arrangement. The question of a standard maintenance agreement is very much more difficult, but I think something might be done. There is also the question whether a maintenance agreement is really a satisfactory method of dealing with batteries, because I am afraid there is a tendency on the part of some members of central station staffs to regard maintenance agreements as relieving them of all responsibility for looking after the batteries. One point must not be overlooked in connection with maintenance, namely, that the life of a battery depends more upon the number of discharges than upon the period of time the battery has been in use. The author has something to say about paint, but he has not mentioned one alternative which I think is even better than paint, and that is "Carbolineum" put on hot. It does not look so well, but it lasts 10, 15, or 20 years, and keeps the wood perfectly sound. The disadvantage of paint is that it has constantly to be renewed and is very liable to peel off. The author says that each cell requires a pressure of 2·75 volts at the end of the charge at the normal rate. I think such practice would lead to batteries being very seriously overcharged. I can only speak for the form of battery in which I am particularly interested, but 2·6 to 2·7 volts is a much safer figure. The author might also give us cadmium readings on charge as well as on discharge, because with large batteries especially it is very difficult to judge whether positive or negative plates are gassing, particularly with wooden separators. Is it really the case, as one speaker said, that batteries have increased in cost during the war more than generating plant?

**Mr. L. B. Atkinson**: One or two speakers have referred to battery-room floors, and I might give a little information which perhaps may be of interest. These floors, where subject to constant wetting with acid, present the same problem as floors in pickling rooms, such as the pickling rooms in the South Wales tinplate works, or in the hollow-ware factories in the Midlands. I was responsible for putting down such floors in the Midlands a year or two ago, and I endeavoured to find out what they should be made of and how they should be jointed. The floors eventually put down were of Staffordshire blue bricks, which everybody, I think, is agreed are absolutely proof against acid for all time. The question of jointing and the sub-base is more difficult. The Home Office put me in touch with the engineer of one of the London gas companies, who gave me information as to supplies of coal-tar pitches which would stand acids indefinitely. Asphalts have been referred to in the discussion. Strictly speaking, I think the term asphalt means a mixture of natural bitumen and lime compounds, and I know of no asphalt company which would offer anything of this kind as acid proof. So I think we must be a little guarded in the use of asphalt. If we use these Staffordshire blue bricks as the mechanical structure, and for the joints one of these gas-tar pitches, I am quite sure we can get a perfectly tight floor and one which would last indefinitely. I only make this suggestion for what it is worth and not from any experience of battery-room floors.

**Mr. R. Rankin**: The author starts his paper with a rather formidable list of obstructing factors. The nature of some of these is sufficiently striking—for example, "irreconcilable prejudice against batteries"—and I think he has done well in giving prominence to them. The one mentioned carries its own condemnation on the face of it. I agree that to the mechanical mind a battery seems rather an unmechanical contrivance; but the mechanical mind, although it is often assumed to be so, is not always the engineering mind—a fact which is frequently overlooked. There are a few points in the paper which I shall deal with briefly. First, there is the provision of a suitable water supply. Some battery makers have, in the past, granted permission to engineers to "top up" their batteries from the mains. I recall one instance in which there were two supplies which could be taken through the system of piping in

* *Journal I.E.E.*, 1917, vol. 55, p. 254.

the station. One supply which had been analysed and found suitable was usually turned on, but sometimes the other was used and the cells were topped up with absolutely unsuitable water, with disastrous results to the plates. It was some time before the battery makers found that out. With regard to getting rid of waste acid, the author does not suggest a method where a large quantity of acid has to be run away. In such a case as I have mentioned, the acid having become unfit for use, it would be useful to know what he considers to be a suitable method. On page 495 the effect of low temperature in lowering the discharge voltage is referred to, which means an increase in current for the same activity or number of watts. This may be somewhat puzzling, for, on, say, a lighting load a lower voltage can only mean a lower current ; it is only when the battery is operated by a booster which compensates for its drop in voltage that extra current is supplied to maintain the activity in the circuit. Although lead-plated conductors in short lengths are common in some classes of battery work, it appears from the paper that the author refers to lead-covered copper rod in long lengths. I should like to ask him if copper rod can be obtained thus lead-covered, and, if so, whether the covering is in the form of plating. The forces between parallel current-carrying conductors are referred to as enormous, and I think misconception may arise on this point. The force is not what would generally be called enormous. For example, the force in the case of the Eagle-street battery at 6,000 amperes, assuming the conductors to have a section of 4 in. $\times$ $1\frac{1}{2}$ in. and to be, therefore, spaced at a minimum distance of 4 inches apart—they are, no doubt, considerably further apart—is $3\frac{1}{2}$ lb. per foot run. I think that if the supports are made suitable for carrying the conductors satisfactorily from a mechanical point of view, without undue sag and, therefore, spaced at reasonable intervals, there is not much risk of their touching on account of attraction or repulsion. The short-circuit current on individual cells is limited by a resistance on the cell-regulating switch and, in the case of a short-circuit on the mains, only the outers of the battery would be affected and they are usually a considerable distance apart. The author gives a list of desirable accessories but does not mention a milking booster. This should be provided, and both it and the main charging boosters ought to be of adequate capacity. In the matter of standardization I think the question of auxiliary plant ought to be taken seriously into consideration. There would be a very great deal less trouble with batteries and much less mistaken prejudice against them if auxiliary plant were taken in hand and suitable standards laid down. I should not be in favour of too rigidly standardizing the minimum weight per ampere-hour of a cell ; every encouragement should be given to research aiming at producing reliable and durable cells to give the maximum output per unit of weight. As regards the freeboard above the plates, this must be greater with deep than with shallow cells, and it is more important than might be thought. As sometimes happens, there may be two cells, one deep and one shallow, doing the same work, both of the same capacity, both containing the same amount of electrolyte, and both giving off the same amount of gas on charge. The drop in level of electrolyte in the shallow cell will be less than that in the other, and the point requires careful watching. There is another very important point ; the deep plate may apparently be gassing very freely when it is not fully charged, as the gas will make a great show at the top of the electrolyte. In fact, if the state of the shallow cell is taken as an index of that of the deep one, the latter only being topped up with water and considered to be charged at the same times as the former, only trouble can result. A great deal of discretion must be exercised in the taking of cadmium readings ; they are very different on discharge from what they are on charge, and the paper only gives specimen discharge readings. The positive and negative plates are, as indicated by the voltmeter, both positive to the cadmium on discharge, but, whereas the positive plates are still positive to the cadmium on charge, the negatives, at the end of a full charge, are negative to it. Badly treated and sulphated cells have a very high potential difference on charge, and analysis of this high voltage by means of a cadmium test-piece may give rise to very misleading impressions. Moreover, the value of the cadmium readings may vary very considerably from point to point in a cell. At the end of a 5-hour discharge to 1·8 volts the following readings were taken at different points in a cell : (*a*) between positive and cadmium 1·99 volts ; between negative and cadmium 0·19 volt ; (*b*) between positive and cadmium 2·06 volts ; between negative and cadmium 0·26 volt. A cadmium test-piece, therefore, in the hands of a battery attendant might serve anything but a useful purpose. The author might state after what number of, say, 3-hour discharges he considers a battery should require cleaning out for some definite proportion of mud-space to plate depth. In regard to overhauls, there are instances in which cells have been quite satisfactory until renewal of positive plates became necessary. Inadequate capacity of charging plant and the tendency in some quarters to work the battery up to its full capacity or more have then led to very serious trouble. Engineers should recognize the great importance of adequate charging rate and amount of charge and light working during periods of re-plating in cases in which it is not possible or convenient to take the battery altogether out of circuit. Referring to Fig. 1, while the curves exhibit the same general characteristics as are shown in other published data, the values for change in capacity per degree variation in temperature appear to be much less than those hitherto given. The values for percentage variation in capacity per degree Centigrade, based on the capacity at 60° F. deducible from the author's curves are approximately : at the 1-hour rate 1·5 per cent ; at the 3-hour rate 1·01 per cent ; at the 5-hour rate 0·0 per cent ; at the 7-hour rate 0·82 per cent ; at the 10-hour rate 0·75 per cent. Figures given by Heim for cells fitted with Planté positives and pasted negatives, by Liagre for cells fitted with positives and negatives of the Planté type, and by Lyndon for cells of an unstated type, are considerably higher. At the 3-hour rate, for example, they are, respectively, 2, 1·7 and 2·5 per cent. It would be very useful if the author would state the type of

negatives and the capacity of the cells which were tested in order to obtain the curves shown in Fig. 1, and how he can account for the difference mentioned.

**Mr. E. T. Williams:** I should first like to refer to the prejudice against batteries. I feel that, of all the difficulties battery people have to overcome, prejudice has been perhaps the greatest and probably the least justified. This is very largely due to those who are in charge of batteries not appreciating that if they will only attend to the small defects in time, the batteries can very easily be kept in order. Many batteries are placed in most unsuitable places. A lot of money is spent on a valuable battery, and very often it is put into a place which is not good enough for anything else. I think it ought to be the reverse—that if any plant requires decent housing it is the battery, because those who have to attend to the battery find the conditions unpleasant enough without the battery room being cramped and badly ventilated and having various other disadvantages. Then another very common fault I find in batteries is this. A battery has been designed of the right size at the earliest stage of the undertaking, but soon the undertaking expands to a far greater extent than anybody anticipated, and I have seen many batteries ruined because they were not large enough. I think the question of milking boosters too, though a detail, requires to be kept well in mind, for it is in these matters of detail that battery work is so very important. Then, again, a battery is very often installed by the engineer, who understands how it ought to be used, but unfortunately the staff either do not understand the battery and do not make the correct and best use of it, or else they will not take the trouble. I think that if responsible engineers install batteries, they should take steps to see that these are intelligently used. I was told the other day on good authority that an acid-proof cement has been made; if this is so, it will be of great advantage in connection with battery floors. Apropos the question of standardization, I suggest that the British Engineering Standards Association might note that batteries for the tropics require more room for expansion of the plates. Some battery makers do not allow sufficient room in their cells and the plates in expanding get up against the sides and buckle. I think the point about specific gravity and higher temperatures is very important for batteries used in tropical climates and that care should be taken to have this understood by the users. In my opinion battery makers would be well advised if they not only encouraged, but also sought in every possible way to get maintenance agreements for all their batteries. I am not quite clear from the paper whether the stand-by batteries referred to are intended to be used only in case of breakdown, or as a kind of peak battery and stand-by battery, because it seems to me that the large batteries of the future will have to be able to meet short heavy peaks as well as act as a valuable reserve. Some years ago I had to get out a scheme for an electric lighting and power supply for three small towns situated close together. Three alternatives were considered, viz. separate stations, and one central station with three-phase or direct-current distribution with or without batteries. I was interested to find the very strong case that could be made out for three batteries, one in each town, supplied from a central station. It enabled very much smaller mains to be laid, a smaller plant in the single station, and it gave a high load factor, which is so very desirable. If the prejudice against batteries were not so strong, I think that in isolated instances like the above they would probably be very much more used. I should like finally to refer to the question of installing batteries on consumers' premises. I think this is a point to which battery people might pay more attention. If by installing a battery on a consumer's premises his load factor could be considerably increased he would be able to get a very much better tariff from the power company. Nearly all agreements for supplying energy are now based on load factor, and the load at some works may be such that they can avoid these peaks—which decrease their load factor—and thus get much better terms. I think that in suitable instances the power companies ought to encourage the installation of batteries on consumers' premises.

**Mr. P. F. Allan:** In any consideration of standard specifications or conditions appertaining to batteries, the question of housing should be considered along with the battery. The provision of proper housing, as the last speaker has said, has a great deal more to do with the efficient work of a battery than most people realize. The other point is that in considering batteries for abroad the author himself has dealt with climatic conditions almost entirely on the question of temperature. Now temperature is by no means the only factor. The relative humidity of the atmosphere may have a great deal to do with many of the difficulties which have been experienced in connection with the working of batteries. For instance, extreme dampness may affect the operation of end-cell switches. Extremes of dampness or dryness affect evaporation and gassing and the degree to which acid spray is carried. People in this country have no idea of how far-reaching the effects of these variations in humidity are. I think that point should be considered in any standard specifications which may be brought forward.

**Mr. G. Broughall:** A number of speakers have referred to the question of battery-room floors. The company with which I am associated have at present nine large batteries in service in traction sub-stations, and in all cases the battery-room floors are of concrete floated with cement. These floors have so far proved entirely satisfactory and show no sign of deterioration. In our case the floor does not get wet with acid, possibly because under our conditions of working, with reversible boosters, there is very little gassing. The batteries are given a gassing charge about once a week and reach gassing point for about a minute or so each day. As regards the conductors, bare aluminium rods with welded joints and coated with acid-proof paint make an excellent job, but all conductors should be very rigidly fixed. The short-circuit current from a large battery is far in excess of the 6,000 amperes mentioned by one speaker. The effects of short-circuits, to which railway batteries are particularly liable, may throw very heavy stresses on the supports. In heavy electric railway service, it is essential to have a quick-acting

reversible booster in series with the battery to obtain the proper output from the latter. In cases such as occur on our system where the instantaneous peaks are four or five times the average load (considering individual substations), the rotary converters take one-third or less of the maximum load, the battery instantly picking up the remainder. We used Entz automatic regulators and find them exceedingly well suited to railway service conditions.

**Mr. H. M. Sayers** (*communicated*): The author places first among the obstructing factors to the development of large batteries: "Irreconcilable prejudice against batteries." It may be well to put on record some of the origins of this prejudice. Perhaps the strongest reason is the liability of a battery to be very seriously damaged or even ruined by a very short course of ill-treatment, the result of ignorance, neglect, or even accident. Except to the expert, an ill-treated battery gives no sign at the time. It is only when the damage is done that the battery fails to do its duty, and is found to require expensive renewals. A boiler, engine, or generator may be seriously damaged by transitory ill-treatment, but usually such treatment will be detected by ordinary supervision or by the attendant himself and terminated before heavy damage is done. It is very difficult to convince the user that the trouble is due to the ignorance of himself or his staff; he condemns the battery as an unreliable and messy contrivance, and avoids it in future. Short of this, there are many cases in which engineers have been "let down" by batteries. Nothing is more exasperating than to find the battery on which one is depending to tide over a peak or emergency load dropping below a useful voltage long before it has rendered the service required. The engineer whose training is more mechanical than electrical, and much less chemical than either, is particularly apt to become impatient under such experience, because he can see nothing to do to help matters, and the causes are not easily evident. A particularly disappointing case of this kind is to find that a battery of which little use has been made is full of buckled plates and sediment, and quite useless when the rare emergency arises for which it was to provide. This state of things was not extraordinary 20 to 30 years ago, when even battery makers gave instructions for the care of batteries which increased experience and knowledge have shown to be wrong. For example, the charging of batteries to the gassing point was stated to result in rapid deterioration, and the end charge voltage was understated. The remedy for this is obviously the training of battery attendants for their duties, and giving such trained men positions of recognized authority so that the utility and life of a battery shall not be jeopardized by shift engineers who, in their perfectly proper desire to minimize the running of boilers and generating plant, may put upon the battery a greater burden than it can bear, or cut down the charging before it is adequate. It is not difficult to train men to the routine work of battery attendance and maintenance. Thirty years ago I erected, put to work, and maintained in good condition and full capacity for several years a battery which was a large one at that time, in a foreign country with the sole aid of two or three illiterate but intelligent native workmen who had never seen a battery before. But to detect the first signs of trouble and to prevent its spread something more than routine training is necessary. Therefore every battery should come under the view of a man experienced, not necessarily in the manufacture, but certainly in the care of batteries. In respect to maintenance agreements, it seems that it would be fair to the maker that the user should employ properly qualified attendants. But the user of large batteries has so much at stake that he will—if ordinarily prudent—ensure this himself, and then it becomes a question whether a maintenance agreement is worth while, except in the form of a guarantee against material or manufacturing faults which manifest themselves after acceptance. No engineer asks for a maintenance agreement in respect to boilers, engines, and generators. In the case of batteries the maintenance guarantee has been demanded partly as a result of the unhappy experiences instanced above, partly because engineers have felt their own ignorance in respect to batteries, and partly given as a form of advertisement. It is possible that manufacturers of batteries have felt that they did not know as much as they would like to about the performance of their batteries over an extended period of use, and have not been unwilling to learn in this way. It can hardly be doubted that they have profited greatly, and that the knowledge so gained has not only been that of what batteries of given types can be relied on to do, and how they should be treated to obtain reliable service, but has also led to improvements in manufacture and design, especially in facilitating maintenance and repair operations. Granted this, and admitting that finality has not been reached, it remains a question whether the insurance of the maintenance of capacity is most economically obtained by the user by entering into a maintenance agreement, or by employing a competent staff and providing a repair outfit. This is clearly a matter for consideration whenever the magnitude and importance of the battery reach certain limits. If a competent staff is necessary for operation, may it not be so equipped that it can do all that is necessary for maintenance? In discussing the curves of output as affected by temperature the author indicates the effects of high and low temperature, but does not indicate what temperature gives the best all-round result. Perhaps this is impossible as a generalization. At high temperatures the battery has greater capacity and efficiency, but the life of the plate may be shortened. It therefore seems to be a question of balancing the value of the higher efficiency and capacity against the increased cost of maintenance. These values will vary in different circumstances. But as it frequently happens that the temperature of the battery room can be regulated at little cost, some indication of the magnitude of the effects would be useful. As even modern batteries do sometimes "weep" acid, it may be of interest to state that boxes or trays filled with whitening placed so as to catch the drops have been found effective in preventing annoyance, also that chalk or other lime-stone is the cheapest neutralizer for waste acid, and easily introduced into the discharge in the form of coarse powder.

**Mr. E. C. McKinnon** (*in reply*): My appeal for standardization was met more than half-way by the President (Mr. C. H. Wordingham), and it is hoped that a recommendation coming from him to the various Committees will bear fruit.

Captain Taylor desired to know the prices of stand-by batteries compared with ordinary stationary batteries, but pre-war prices are quite obsolete and post-war prices are problematical. If based on capacity the prices of the two types would closely approximate. If based on weight the stand-by battery would be considerably cheaper.

The tiled floors referred to by Messrs. Crawter and Brazil were evidently set in cement. The uncertainty of asphalt emphasizes the need for standardization in this branch also. An interesting experiment which came under my notice was made to determine the effect of vaseline in protecting aluminium. The current for charging a large number of batteries in a shed 50 ft. × 300 ft. was distributed by means of heavy aluminium conductors. Some of the bars were bare, and others were coated with vaseline. All the bars so coated were still equal to new when heavy corrosion had been set up on the unprotected bars.

Mr. Brazil mentioned buckling as an ordinary phase in the life of a battery, but no instance of buckling occurred during nine years' working in a Chloride battery at the Fisher-street station of the Metropolitan Electric Supply Company, using this merely as a typical instance to illustrate that buckling is not a normal feature of an old battery. A more practical device for detecting internal short-circuits than the sensitive galvanometer is a small magnetic compass. The tests referred to in the paper were the official taking-over tests —not periodical "snap" tests. It would surely be complacent to "make allowance for a few cells that drop out" in any test on a new battery. No definition of a large battery was supplied to me when invited to write the paper, but batteries which give in the aggregate 25,000 amperes at 200 volts for 1½ hours are certainly included in the category. To specify a 10-minute rate may be more traditional than useful. It is a point which might be considered in formulating a standard specification. Mr. Brazil's reference to a special type of booster was a valuable reminder.

Mr. New spoke with the disconsolation bred from discouragement, but the hearty support given in so many quarters should be sufficient to spur him to fresh efforts to gain his points. His advocacy of "Carbolineum" as a substitute for paint is worthy of note. He has misread the facts given in the paper regarding the maximum charging volts required by a cell. Unfortunately, one is not able to decide what is a safe charging voltage for a stationary battery. The characteristics of the cell determine the maximum volts required to charge it fully. One incidental advantage of wood diaphragm separators is that they assist in judging the gassing of the respective plates.

I can support Mr. Atkinson's recommendation of blue vitrified bricks set in pitch for battery-charging sheds, as this type of floor has been used in battery makers' works for 25 years, but asphalt gives a much smoother surface.

In reply to Mr. Rankin, the lead covering of the rods may possibly enclose the copper or merely form a shield over the upper portion. Copper rod can be obtained lead covered—not plated. I have seen the remains of conductors which have demonstrated the enormous forces exerted between parallel current-carrying conductors under certain conditions. There is much to be said in favour of standardization of auxiliary plant. If it is understood that standards are to be revised at sufficiently frequent intervals, this permits of the introduction of modifications rendered practicable by developments in research and design. In my published notes on cadmium readings emphasis is laid on the fact that too much reliance should not be placed on cadmium readings in determining whether a cell is fully charged. It is not possible to give an unqualified reply to Mr. Rankin's query as to the period for which a battery should work on 3-hour discharges before requiring to be cleaned out, as the method and depth of formation, the type of negative, the mixture of the active materials employed, the working temperature, and the conditions of charging all contribute to the result. The capacity variations due to temperature in Fig. 1 were based on numerous tests carried out on cells of various capacities employing special Planté positives and box negatives. The figures are quite conservative, and are given as commercial values, whereas those cited by Mr. Rankin are laboratory figures disregarding factors pertaining in service.

Mr. Williams gave valuable support to the contention of battery engineers that prejudice to batteries is unjustified. He is evidently not aware of the resentment to maintenance agreements expressed by many contractors and consultants. Mr. Williams made a good case for installing batteries on consumers' premises. Peak and stand-by batteries already exist in many big works, and if the generating plant is substituted by bulk supply the battery might very well be retained.

Mr. Allen raised a very useful point in connection with tropical conditions. These clearly call for quite different treatment of a battery from that recommended in temperate climates.

Mr. Sayers gave a series of explanations for prejudice against batteries, and also reasons for their failure in central stations. His suggestion at this stage that battery attendants should be trained for their duties so as to prevent shift engineers jeopardizing the life of batteries indicates an unfortunate state of affairs for which battery makers have too frequently borne the loss. One very common argument in favour of maintenance agreements is that engineers whose batteries are under maintenance will not have to apply to their committees for a large sum out of revenue for battery repairs in any one year. Some committees, it is true, set aside for battery repairs an annual amount equivalent to the maintenance premium offered by the battery maker, but if the repairs are necessary before the amount involved has been accumulated the engineer has a bad time, or renewals are ordered from another maker. It is generally recognized that the range of temperature under which a battery gives the best results is 50° F. to 80° F.

North Midland Centre, at Leeds, 12 February, 1918.

**Mr. R. H. Campion:** The question of whether a battery should be installed or not on direct-current systems often hinges on other considerations than capital cost, and one remembers with joy the time when on a faulty machine being cut out the load could be taken by the battery; but I do not think it is possible to do this now in any fairly large station. The big batteries that have been installed in this country are not capable of taking the whole load for even 5 minutes. I think, therefore, there comes a time when either the maintenance contract or the battery requires renewal and when the question arises as to whether it pays to have a battery and, if so, one of much bigger capacity. If one is to be guided by the 10 obstructing factors set out by the author I am afraid in most cases one would not install batteries. Suppose an enthusiast decides to try to overcome all the obstacles mentioned; will he be encouraged by the makers with a reasonable maintenance contract for, say, a period of 10 years. Some maintenance guarantees are not worth the paper they are written on. I wish particularly to refer to the maintenance guarantees some makers offer for batteries on electric vehicles. I think that if they would be more reasonable, or meet the wishes of the user, the electric vehicle battery would stand a considerably better chance than it does at present. A sphere in which I have found batteries to be useful and profitable is in taking traction peak-loads, and if it were not for the reversible booster we should have to be stricter in restricting consumers to their agreed-upon maximum demands. In this connection I am sorry the author has not mentioned the City and South London Railway battery lay-out. Some years ago that Railway had a very ingenious arrangement. They generated 500 volts direct current, and by means of a battery placed farther up the line were able to obtain a pressure of 1,000 volts. I thought it was going to bring battery work more into prominence than it did. I am sure we are all grateful to the author for pointing out the ideal conditions for the housing of batteries, and one only hopes that the cost will not put the battery out of court. It has to be remembered that the period over which batteries can give their output is generally only about 1 hour, and the cost is usually about £10 per kilowatt. Up to now one has been content to leave the question of standardization to the makers, and I still think there is no question that this practice must continue. It is for them to agree on standardization, and it should be easier owing to the recent amalgamation of battery makers. I think it would be a great advantage to have specifications standardized and revised every 3 years, but I do not agree that it is always such a simple matter. The author mentions, for instance, the number of cells for a given busbar voltage; this may be determined by the way the battery is connected up and the resistance of the lead connecting-bars. I had a case where, owing to the battery being connected up in a different manner at the time of the test, the pressure was about 10 volts low. That meant additional cells to make it up. It was easier and cheaper than reconnecting the bars. From the particulars given on pages 500 and 501 I notice that, of all the classes mentioned, none is any better than the others from the maker's point of view.

**Mr. W. M. Selvey:** One really leading statement in the paper on the question of policy, which is the thing we are all interested in to-day, is on page 504, namely, "American engineers claim that developments are bound in time to lead engineers here to adopt the same line of policy as theirs, as the smaller stations become absorbed and bulk supply becomes more universal." This question of bulk supply is to-day before us more and more. The author throws down the "gage" there, and does not base his opinion so much on his own experience as on the experience of American engineers, which leads them to say that "it is no use considering bulk supply unless one goes in for big batteries." That is how I read it. Again towards the end what the author says amounts to this: In the early days we used batteries for all sorts of purposes for equalizing the load, and perhaps for making power stations more efficient, filling up the night gap, the dinner-hour gap, and many other things, but to-day it has become purely a question of stand-by. That is, in order to take the full supply of the "bulk" we have to install a big stand-by battery purely as an insurance. If that is so it is one of the most serious statements in the paper. I appreciate we shall always want batteries for some purposes, but the idea that they will have to become general for bulk-supply systems is certainly somewhat new to me.

**Mr. T. Roles:** On the first page of the paper the author expresses the opinion that more progress would have been made in the development of large batteries if it were not for many obstructive factors, a number of which he sets forth. The first to be mentioned is "Irreconcilable prejudice against batteries." I must say that personally I have that irreconcilable prejudice, but it has not blinded me to the many advantages which accrue from the installation of batteries in connection with direct-current supply systems, and to substantiate this statement I may say that, on my advice, the Bradford Corporation has during the past few years installed a large battery which was manufactured under the author's supervision, and I am pleased to say that it is operating very satisfactorily. In addition to this we have a battery which may even now, I think, be regarded as of medium size and a comparatively small one for emergency purposes in connection with the works lighting and trip circuits. Years ago it was unfortunately my duty to look after various batteries, and my prejudice is due to the fact that often in the night I have had to go round with a lamp and stick removing lumps of paste which had got between the plates. I remember being very glad when I left a direct-current station and went to an undertaking working on the high-tension, alternating-current system, to know that there was no battery in the latter. The difficulty in providing the necessary capital to cover

the cost of a large battery is often very real, as unless an undertaking is in a very sound financial position those responsible for its management hesitate to risk the large expenditure involved. The difficulty is increased by the attitude adopted by Government Departments, as the Local Government Board have decreed that loans in connection with storage batteries must be repaid within a period of 7 years, in spite of the fact that battery makers of high repute will guarantee a battery for 15 years. It follows that, in addition to paying the maintenance charges, an undertaking has to repay one-seventh of the cost of the battery each year for 7 years, and also to pay interest on the outstanding capital sum, and therefore, unless very appreciable economies in works costs are effected as a result of the use of the battery, the profits of the undertaking are considerably reduced, and may even be wiped out until the loan is paid off. In the interests of a cheap and reliable supply of electricity in this country it is to be hoped that the Local Government Board, or whatever Government Department may hereafter be the authority for the sanctioning of the raising of loans for public electricity supply, may be prevailed upon to increase the periods for repayment of loans sanctioned in connection with the purchase of large batteries, provided satisfactory guarantees are obtained that the battery will be efficiently maintained throughout the term of the loan. I would suggest that a period for repayment of at least 15 years should be allowed under these conditions, and, taking into consideration that a battery is a valuable asset from the point of view of its scrap value alone, it appears that little risk would be incurred if the period were made still longer. Speaking from memory, the Bradford battery cost something over £14,000, under pre-war conditions. If equal repayments of capital are made these would amount to about £2,000 a year. Then there is the battery maintenance, which comes to nearly £1,000. That is about £3,000 a year, and, to this, interest on outstanding capital must be added, while further sums must also be set aside to cover interest and repayments on the capital cost of the building (which is necessarily heavy because of the substantial construction), the heavy cables between the battery and the switchboard, the very heavy switchgear and the regulating boosters. Altogether a battery of the size of that installed at Bradford involved a capital outlay of not far short of £25,000 in pre-war times. Under the conditions mentioned, one needs to have great faith in the advantages to be derived from the use of large batteries before deciding to purchase one. The factors which led to the installation of the Bradford battery were these:—We have a very large three-wire direct-current system from which supply is given to the central area of the city. This system was until some years ago supplied by a considerable number of comparatively small generating sets the breakdown of any one of which would be unlikely to affect the continuity of supply. During the past few years practically the whole of the works output has been generated by turbo-alternators of fairly large capacity, and the direct-current system has been supplied by means of rotary converters, each having an output of from 1,500 kw. to 2,000 kw. In order to ensure continuity of supply it was deemed desirable to install a battery capable of taking up the load which would be dropped by one of those rotary converters, in the case of a breakdown, until one or more direct-current generators could be run up and switched in. Consideration was given to the question as to what economies could be gained by running fewer boilers and by running the steam plant under better load-factor conditions. Mr. F. H. Whysall read a paper* before this Institution some years ago in which he claimed that very considerable economies were obtained by the use of the large battery at the Manchester Corporation's Dickinson-street station. We at Bradford, however, could not see that under the conditions under which we were then working we should experience any direct saving in £ s. d. by the installation of a battery. From what I remember we came to the conclusion that, if anything, we should be somewhat out of pocket, but we thought that the amount we should be out of pocket, if any, might well be regarded as an insurance payment for continuity of supply. Another obstructive factor mentioned by the author is the "Reluctance to allocate adequate space to batteries." I myself think that there is not so much reluctance amongst engineers in allocating adequate space to batteries as there is real difficulty in finding adequate space for them on existing sites. It thus often becomes a question of either doing without a battery or installing it in a position recognized as unsuitable. Much exercise of ingenuity has often to be resorted to in providing accommodation for a battery, and in Manchester, I believe, a special room had to be constructed over a boiler house for this purpose. I heartily agree that the inadequate training of engineers has had a very obstructive effect on the installation of large batteries, as this has resulted in the ruination of many smaller batteries used in connection with public supply undertakings and private plants. Storage batteries generally have, as a consequence, come to be regarded by many as unsatisfactory and unreliable. In most places the duty of looking after the battery is allocated to several of the engineers in the works, not one of whom has had any particular training for this class of work. No one is held directly responsible for its care and maintenance, and this is not a job which is sought after. What happens is that the battery is neglected, and no battery or any other portion of a works plant can be expected to work well under those conditions. If a large battery is to prove a profitable investment it should be placed under the direct supervision of one engineer who has had considerable experience of battery work, and who is sufficiently enthusiastic to make its care and operation a close study. There are any number of points in connection with this paper about which one might talk for a considerable time. For instance, there is the question as to what is the best material to use for flooring in battery rooms. Personally, as a result of a somewhat long experience, I have always inclined to the use of an asphalt floor. Such floors, however, do not always prove satisfactory. The first of such floors to come under my notice was covered

* *Journal I.E.E.*, 1913, vol. 50, p. 376.

with an asphalt which softened considerably with a comparatively slight rise of temperature, and matters were made worse in this respect in that the battery room was situated over the engine room. Heavy articles placed on this floor soon left their mark and if allowed to remain for a few weeks had to be cut out. I next had experience of a lead flooring. That was all right if one was careful to carry about an insulating mat on which to stand when inspecting cells and in seeing that the insulating mat did not get wet with acid. The lead floor in that battery room had to be removed to relieve the weight on its supporting joists, the stresses on which were found to be too high. Incidentally, this is a point to which careful consideration should be given when designing battery rooms, as from my own experience I have found that architects, probably as a result of not being given sufficient information, are prone to give the floors too little support. It was decided to substitute asphalt as being much lighter. I had a number of asphalts tested and found that but few could be regarded as acid-proof, although all were supposed to resist the action of acid. A further difficulty arose in obtaining an asphalt which while being acid-proof was sufficiently hard to stand wear and tear, and which would not soften under such changes of temperature as are ordinarily experienced. A suitable asphalt was, however, finally obtained, and asphalt from the same firm has been used at Bradford and has proved equally as satisfactory as it did in the battery room which I first mentioned.

**Mr. R. D. Spurr:** I should like to make a few remarks with regard to the operation of large batteries. The author has stated the makers' views about them, but I should like to say one or two things from the operator's point of view. With regard to the ventilation of the battery room and the use of a fan, I think a chimney would be better. Suitably proportioned chimneys will draw off the gases, and, provided the air inlets are at the floor-level and are well distributed, all dirt and grit will tend to settle on the floor, where it can be easily washed away without causing any dust. Fans are unsatisfactory on account of the acid spray corroding the blades; they create a strong draught unless fitted with a speed regulator, although the latter will be useless, as the attendant will always prefer the top speed, but he cannot assist ventilation when a chimney is provided. Although we do not get extremes of temperature in this country, it seems a wise provision to provide a low-pressure steam heating-system for use in the winter, as the demands on the battery are just as great but more frequent than in summer. In addition to the standards suggested, it would appear that the life of a battery could be better expressed as the total number of complete discharges and charges that constitute its life, say at the 5-hour rate. Batteries could then be rated as suitable for 500, 750, or 1,000 complete discharges and charges, as the case might be, and users would then form a better idea of the useful life remaining in their battery by deducting the number of discharges taken out from the total rated life. I suggest that a sheet of glass be put at each end of the cell, leaving about an inch between this plate and the lining. This would prevent the end negative element from touching the lining, and would also allow the necessary make-up water to be introduced at the bottom of the electrolyte where it would stir up and mix with the heavy acid lying there. The channel bars now used seem to me to be far too rigid. They should be made of a deeper inverted U section to allow for the working that is constantly taking place. The growth of the positive plates in the Planté type is always present, although the improved Planté type does not grow at all. It is almost an impossibility for any movement to take place at each end of the plates. This points to the necessity for a more flexible connection between cells and would probably prevent the evil of broken supports. If one carefully examines the cells it will be found that the end cell of a row does not show such badly buckled plates as others in the same row, particularly where the last channel bar is positive. Specially designed insulators should be freely used between cells so that one supports the others. I suggest that these insulators be made cylindrical, not less than 4 in. in diameter, and perfectly smooth, except for a single collar in the centre to allow any moisture to drop away from the boxes. The ends should be recessed to take a small wooden dowel to keep them in their places; such insulators could be easily cleaned and inspected without disturbing them. Ampere-hour meters, recording ammeters and voltmeters do not show the exact condition of the battery, whether it is discharged or partly so; but the hydrometer, which will give a very true indication of the state of the battery, is a very indifferent instrument to use. If the acid is at all low in the cells it is almost impossible to get a correct reading and, again, no two observers get the same reading in the same cell. What is wanted is a recording instrument that will give a graphic record of the rise and fall in specific gravity as the battery is charged and discharged. The syringe type of hydrometer used for electric vehicle batteries is a decided improvement in this direction and, though useless for central station work, might be altered so as to give the limit of readings required and thus carry us on until a recorder is designed. Too much floating results in very inefficient working. A battery can be left floating so long that it becomes completely discharged. In my opinion a stand-by battery should be discharged and charged at least three times every week in order to obtain a reasonable return for the capital expended in the battery. Very large batteries are quite easy to work with hand-regulated boosters, and the total booster capacity need only be large enough to carry the current at the 1-hour rate of discharge; under any abnormal conditions the switchgear should be designed to connect the battery direct to the busbars, leaving the boosters running idly; this method has been quite satisfactory in operation, and tends to prove that end-cell regulators are an unnecessary evil. Although the modern types may be capable of handling heavy currents, in actual operation the end-cell switch will hardly be used, as abnormal occurrences call for a quick automatic action and under these conditions voltage regulation is unnecessary. When using emergency batteries on three-wire systems, and the boosters are out of circuit, the voltage cannot be regulated, but it might

be possible to use a modification of an end-cell switch at the middle of the battery for connecting the middle wire to any one of four or six cells. This would give quite sufficient voltage variation and would only need a comparatively small switch.

**Mr. J. H. Shaw:** I think the author has been a little unhappy in selecting America for our guide. He gives an instance of a battery capable of discharging 80,000 amperes in 10 minutes. If this battery were used in conjunction with a three-wire system at the usual pressure in this country of 500 volts across the outers, the energy available would be approximately 40,000 kw. We do not have such blocks of flats in England as in the States, and consequently to distribute 40,000 kw. in a city for consumers each only requiring a relatively small amount of energy would require an enormous amount of copper to be buried in the ground. The problem of electricity supply in England is, I believe, being tackled in time. The generating works have not grown to the size they have in America, and English engineers have recognized the economical limit of direct-current distribution, which is being strictly confined to central areas, with alternating-current distribution and static transformer substations on the outskirts. The use of batteries in the future will be confined to hospitals, telephone exchanges, and telegraph offices, where it is essential there should be continuity of supply, and such other places as care for luxury. One would not have much faith in power-station engineering if we thought that large batteries at the works and in substations were essential to obtain continuity of supply. I believe that with proper design and reasonable interlinking between the large stations, with perhaps the use of batteries for excitation, a supply of electricity can be given equally as reliable as our main-line railways. The summary of specifications, pages 500 and 501, is very interesting and instructive. The author must, however, remember that it is difficult to specify exactly how one wishes plant to be constructed. If the purchaser is familiar with goods of a certain make he consequently draws up a specification which, while favourable to one firm, may rule out two or three equally good manufacturers who arrive at an equivalent result in a different manner. With regard to standardization, this is entirely a manufacturer's problem, and it is impossible for the user to do more than accept the maker's standard plant which appears to be the most suited for the work under consideration. I agree with the author that a standard maintenance agreement is required, as what the author calls the observance of reasonable instructions is not reasonable from the user's point of view; for instance, one of the instructions is that the full output shall not be exceeded in any period of 24 hours. One of the speakers said that we must obtain full output at least three times a week. I maintain that to make a battery installation a paying proposition full output should be obtained twice a day.

**Mr. L. Broekman:** Mr. Shaw's contention that a battery, to be remunerative, should be discharged twice a day is not borne out by actual results. As to booster control versus end-cell regulation, personally I am in favour of booster control. To begin with, it reduces the number of cells needed, and therefore decreases the capital outlay. Then the copper or aluminium, whichever is used, has to be brought to the end cells only, and conductors to the regulating points can be avoided; also the extra cost on the charge and discharge switches. As to the energy consumed in running the motor of a booster set on discharge, it has to be borne in mind that this is partly compensated for on charge by the smaller number of cells which, on a 500-volt circuit, may be the difference between 250 cells and 280 cells. It has the additional advantage that with a booster one can regulate to a fraction of a volt, while with cell regulation, especially with multi-cell contacts, the jumps from 6 to 8 volts at a time are very perceptible and militate against good lighting service. The likelihood of any falling off in the demand for peak-load batteries, foreshadowed by the author, I do not think need alarm us; the wonderful progress being made in other directions will assure full scope for the activities of those engaged in the industry at present, should it ever come to pass. In electric vehicle and tractor work alone the demand for storage batteries promises to be so great that it will require extraordinary efforts on the part of manufacturers to keep pace with it.

**Mr. E. Balmford:** On page 494 the author mentions the disposal of the waste acid, but does not put forward any suggestions for dealing with it, and he also states that it is impracticable to neutralize large quantities. In many cases any acid discharged eventually finds its way into a river or canal from which water is drawn for trade purposes, the result being that corrosion of pipes, fittings, and other plant with which this water comes in contact, takes place, and in textile works the product is adversely affected. Many cases are on record in which boilers and other plant have had to be renewed after a very short life, solely due to the presence of acid in the water. The question of acid pollution of rivers, canals, etc., is one which requires to be seriously considered. The obvious place to treat any acid is before it is discharged into the sewers, and it would be helpful if the author would give his experience of the methods he has used for dealing with acid, and what results he has obtained. It is manifestly unfair that a user of acid should discharge, without making any attempt to neutralize it, any effluent into waters from which supplies for trade purposes are drawn, and so cause other people a large amount of entirely unnecessary trouble and expense.

**Mr. W. Lang:** There is an apparent contradiction where the author refers to conductors on page 496. At the top of the first column he says that "lead-covered cables are cumbersome," whilst lower down he states that "The most satisfactory form of protection is lead covering with the further protection of a coat of grease or paint." I think he meant in the first case to refer to lead-covered vulcanized rubber-insulated cables, and in the other case to the lead covering of copper conductors or other conductors which may be used without any insulation whatever. It occurs to me, however, to inquire whether the author has ever made any effort to use ordinary conductors with a specially designed cab-tyre sheathing and with-

out any intermediate insulation between the conductor and the sheathing, that is, not to depend on the cab-tyre sheathing of the cables for their insulation but to mount them in the usual way on porcelain insulators as he describes.

**Mr. E. C. McKinnon** (*in reply*): Mr. Campion appears to query, not merely the use of large batteries, but of any battery at all on direct-current systems. When one considers the number of motor-driven auxiliaries in large stations, the time lost and confusion created in a complete shut down, and the advantage derived by ensuring continuity of supply at least in the station, the use of a storage battery appears to be almost a necessity. The additional uses to which it may be put are varied. Mr. Campion testifies to its value in taking the peak loads of traction work, and also refers to the City and South London Railway battery lay-out, which is only one of the many successful applications to which a battery can be put to meet exceptional conditions. The justification for a battery does not depend, as he suggests, on what sort of a maintenance agreement can be obtained; maintenance agreements are not secret treaties, the printed standard forms are supplied free by any battery maker. The subject of the paper is a wide one, but it seems superfluous to introduce discussion on electric vehicle battery guarantees.

Mr. Selvey may be correct in coming to the conclusion that it is no use considering bulk supply unless peak batteries are installed, but this is his own interpretation of the trend of policy which can be traced in American practice. In the first stage innumerable small units were distributed in innumerable small stations, each station having to deal with a night gap, a dinner-hour gap, lighting peak, etc., in the 24 hours' supply. Batteries were found convenient as an auxiliary supply during periods of extremely light or extremely heavy loads, incidentally acting as a stand-by in breakdowns. In the next stage, some of the stations became substations to large ones in which were large units, some of which could be run fully loaded, and batteries improved the efficiency of the stations by levelling the load on running plant and serving as a stand-by for emergencies. In the third stage the larger stations in turn have become substations whose utility as distributing centres is dependent solely on the incoming supply from a central generating station unless a stand-by battery is installed—primarily as an assurance of continuity of supply, but incidentally for various other useful purposes. This stage appears to have been definitely reached in America. Mr. S. L. Pearce does not think it will ever be attained in this country, but Mr. Roles records that insurance for continuity of supply was deemed the first consideration at Bradford.

Mr. Roles deserves congratulations for having overcome his admitted prejudice to batteries to the extent of putting down one of the largest batteries in this country. Our present leading engineers sometimes forget that their adolescent experiences with storage batteries date at least 20 years back, and that the improvements in battery design and manufacture have been tremendous during the present century. Mr. Roles alludes to very appreciable economies in works costs being acquired as a result of the use of a battery in order to secure a profit on the undertaking. The waste of current in unnecessary and undesirable charging is common to most stations. An effective method to bring this waste to the appreciation of those responsible might be to display a notice giving the value of the units so wasted in terms of pence, e.g. "for every minute unnecessary charging, you wear away some of the useful life of the plates which causes expense to the battery maker, but you also waste —— pence of the ratepayers' money."

Mr. R. D. Spurr's views from the operators' side are valuable, and there is something to be said in favour of a chimney and heating system in a battery room. The life of a battery may be theoretically expressed in terms of complete charges—the wear and tear occurring mainly towards the end of a full charge, but in practice the results are so largely influenced by treatment, impurities, temperature, and class of work, that it is absolutely impossible to deduce the useful life remaining in the battery from the number of discharges taken out. A study of any Planté battery will show that space is left between the edge of the positive plates and the supporting glass hangers. The positives are only rigidly held at one side. The "evil of broken supports" can usually be traced to too much charging, or sulphation set up by improper treatment. Inter-cell insulators are in common use in large batteries, although their presence is not entirely advantageous. A recording hydrometer has been on the market for 14 years, but is regarded as an unnecessary refinement. Mr. Spurr repeats the booster advocate's arguments in favour of reversible boosters—hand controlled and automatic—but asks for trouble when introducing automatic throw-out switches, as these are not infallible. All the methods he suggests are in actual use, but the sense of security imparted by end-cell regulators is tinged with tremors in the case of heavy-current automatic gear.

Mr. J. H. Shaw holds out a disappointing prospect for users when he informs them that continuity of supply must be regarded as a luxury, only to be assured of in hospitals. The scrutiny of any battery maker's order books—disregarding temporary conditions created by the war—would show the fallacy of this view. It is impossible to credit that public supply companies, docks, railways, steel works, factories, etc., will all eventually discard their batteries. Mr. Shaw is unhappy in selecting for his argument our main-line railways as a standard of reliability, because every railway in this country employs storage batteries in some form to ensure continuity of supply. He refers to the difficulties of specifying exactly how one wishes the plant to be constructed. This is exactly the point I made, and the alternatives suggested are, not to specify at all unless sure of what one wants, or if sure of what one wants, specify on relevant and consistent lines.

Mr. Broekman puts forward the argument for booster control in inimical style. I agree with him up to a point, but instances are on record where the booster has broken down, leaving the reliable battery ineffective or inoperative.

In reply to Mr. Balmford, for the past 3 years waste acid from batteries has been well worth saving, as it has a good market value, otherwise the most preferable method is to dispose of it by sending it to the nearest acid works.

The cab-tyre sheathing suggested by Mr. Lang would certainly be more suitable than the ordinary insulated, taped and braided insulation. Its use for flexible cables has been found most satisfactory in battery rooms. There appears to be a reasonable preference for copper rods or bars as main conductors to batteries.

## North-Western Centre, at Manchester, 26 February, 1918.

**Mr. S. L. Pearce**: The author has raised several points which can be profitably discussed in the light of the added experience of the last few years and also with reference to the possibilities of the future. So many particulars have been published, and so much detail was given by Mr. Whysall,* with regard to the Manchester battery that I feel there is very little for me to add. The Dickinson-street battery was installed in 1910 and the particulars relating to its performance have been very fully published. That battery was followed some 3 years later by a battery put in by the author's firm which is used exclusively on traction service. Although no particulars of that have been published I may say that it has been, on a modified scale, equally successful as the battery in Dickinson-street, which latter is now used exclusively for lighting and power, and chiefly lighting. I see no reason to change my opinion that a peak-load battery, taken even at the 1-hour rate, effects a saving in capital charges in comparison with steam plant, and is also capable of fulfilling to a very large degree the functions of a purely emergency battery. That is the way in which the Dickinson-street battery is operated to-day. In the winter it deals with about 30 per cent of the average daily peak; on occasions in the summer, during storm loads, it has been called upon to deal with an increased demand of something like 70 per cent. Obviously with that class of violently fluctuating load nothing else than a battery is really equal to the demand and can so readily and economically deal with it. The author raises possibly some new points in connection with the very debateable question of booster control versus end-cell regulation. He suggests that if engineers were able to start *de novo* some might be inclined to reverse their original decision regarding methods of control. I quite agree, and I must confess that I am one of them. Under the actual operating conditions in Manchester to-day, and these differ somewhat materially from the arrangements which were originally proposed and for which the battery was originally designed, I believe that end-cell regulation would show better results than booster control. A point that is very obvious but, I think, is not infrequently overlooked has been touched upon in the paper. The power which is required for the booster plant in order to maintain the busbar voltage represents a very considerable percentage of the battery discharge, and it must be remembered that the maximum output of the battery is generally required at the time of maximum busbar voltage. I can perhaps give some figures in connection with our own battery to substantiate that statement. Taking the 1-hour rate of discharge which the battery is capable of, namely, 8,400 amperes, 1,100 amperes of that total may be deemed to be absorbed by the booster plant, leaving a net battery discharge of 7,300 amperes. Those are the figures at the commencement of the hour. At the end of the hour they are 1,900 and 6,500 respectively, showing a variation over the hour from 13 per cent to 24 per cent; that is to say, out of a total of 8,400 amperes 13 per cent is required by the booster plant at the beginning and it rises to 24 per cent, the booster voltage having risen from 53 to 93. Obviously at the higher rate of discharge this percentage of the power required by the booster plant increases very rapidly. Hence it seems to me that these very high rates can only be obtained with low boosts or possibly with the battery on the bars, without the use of boosters at all. I think, therefore, that in considering the cost of the two systems, working as we are at Dickinson-street, the advantage would rest with the end-cell arrangement. I am pretty sure that would be the case taking pre-war values for the plant. I do not think it will be disputed that there is an increase in efficiency to be gained by the end-cell regulation method of control. In the case of the Dickinson-street boosters with the battery simply floating across the bars, the units used amount to something like 500 a day. I am aware that the total losses in the booster plant and in the batteries are covered some three or four times over by the saving in coal. Still that is not the point in question. I think undoubtedly the end-cell regulation would result in more efficient operation. With regard to stand-by batteries, the author suggests that American engineers claim that future developments will lead English engineers to adopt their policy and to employ batteries for purely stand-by or emergency purposes. With that I wholly disagree and I ask the author to tell us what is really the underlying reason for this practice in the States. Is it not that these large public service Corporations, operating under leases from local authorities and other bodies, have imposed upon them as a condition of their leases very onerous obligations with regard to guaranteeing the absolute reliability of their supply? Therefore I should imagine these purely stand-by batteries are put in at the lowest possible cost per kilowatt by these public service Corporations, more as an insurance against claims for damages resulting from failure of supply than for reasons of economy. From the economic aspect of the question a purely stand-by battery can effect no saving in running expenses; therefore it seems to me a wrong policy, from the financial point of view, to put in a battery simply with this one object in view. There might be something to be said for installing two batteries, one as a stand-by and one for

* *Journal I.E.E.*, 1913, vol. 50, p. 376.

peak load, so as to secure the advantages of both, but I am fairly sure that under the conditions which obtain to-day, and as I think they will obtain in the future, there is not much of a case for putting in a purely stand-by battery in this country. In the discussion on Mr. Taylor's paper * in London some 7 years ago I made some remarks which I adhere to to-day absolutely. I said then that a battery which is large enough to act as a substitute for a peak-load plant on the 1-hour basis ought to give that economy in working and have all the emergency qualities which make it a sound commercial investment. Now it is very interesting—although the author has not given it in this paper—to compare the prices of the two types of batteries, bearing in mind that a battery of "Faure" or "Exide" plates has a capacity something like three times the capacity of a battery of ordinary Planté plates for the same floor space. These are the figures I have extracted from papers read in the past, and figures also that relate to our own batteries at Dickinson-street. On the 5-minute rating the Manchester battery price worked out at £3 15s. per kilowatt. Mr. Taylor stated that the Birmingham battery on the 3-minute rating worked out at £2 10s. per kilowatt. If we compare the above figures with those given by the author for an "Exide" stand-by battery in the United States on the 6-minute rating—viz. £3 per kilowatt—it seems to me that the difference in cost per kilowatt is not very material, and we are sacrificing all the conditions of economy which might result from putting in a peak-load battery. I cannot see where the gain really comes in. I should like to ask the author, in regard to the "Exide" plates, whether the cells maintain their full capacity without being worked and how long that capacity will remain under such conditions. The details given by the author with regard to the Eagle-street battery, particularly with reference to the depth of the plates, are most interesting. One has always had the impression that if a plate much deeper than 30 inches were adopted one was really asking for trouble. I suppose the excellent results which have been obtained with the Eagle-street battery were possibly due to the use of antimonial lead, so obtaining a much greater tensile stress than with the other type. It seems to me that a 46 in. depth of plate is rather a big proposition. I am extremely interested in the results which the author expects to obtain with the Metropolitan Company's plant. With regard to the question of maintenance agreements, the author was hardly fair to local authorities. I think it is always desirable that the acid should be provided by the battery makers under their maintenance agreement. In our own case the author's firm provide it. It seems to me that it obviates a very fruitful source of dispute. It also gets rid altogether of many questions which have been raised by battery makers as to the users providing acid of a wrong quality. With regard to future tendencies, the author has very rightly pointed out the direction in which we are moving and has in his own mind, I think, come to the conclusion that the use of batteries in the future may be less than it has been in the past. I have given my views, for what they are worth, on the question of stand-by batteries. It seems to me that, looking to the future and realizing that in some form or other we are in for interconnection and that interconnection means a greater degree of reliability, the possible use of large batteries in power stations will be more limited in the future. Small generating stations will undoubtedly have to be shut down and such user as there may be of peak-load batteries in those cases will, I think, be more in the direction of getting a very much better rate per unit from the supply authority owing to the load being largely of a non-peak character.

**Mr. S. J. Watson:** The author suggests different types of battery-room floors. I rather fancy that the best form is not a flat tile but one which has serrations across it, so that one walks on a comparatively dry surface, but each tile will drain any acid or moisture which may have been spilled upon the floor. I think the drainage should be carried to more than one position in the battery-room. A battery-room of any size which necessitated the flow of liquid from one end to the other would be in an exceedingly sloppy and uncomfortable condition when any work was going on such as the removal or the washing down of the plates. I think it is therefore essential that a number of drains should be provided and that the floor slopes should be so arranged that the moisture would have to move as small a distance as possible. The disposal of acid is really an important matter. When one has to renew entirely or to overhaul a battery, necessitating a complete change of acid, it is rather a problem how to dispose of the large quantity which has to be got rid of. In my own case, when a battery was being cleaned out some few years ago, it gave the sewage works quite a job to tackle. Had they known where it was coming from at the time they would have put a stop to it. There is no doubt that if a considerable quantity is emptied into the drains, the pipes and joints may be damaged. It is necessary therefore to dilute the acid as much as possible. The author makes certain suggestions in connection with the standardization of batteries. We all admit the advisability of standardization if it is at all possible, but I really think at the present time there is not very much hope of standardization on this matter. Different makers adopt different sizes, widths, and spacings; and it is unfortunate that if we have one type of plate installed and wish to have another type this will certainly necessitate changing the boxes and probably rearranging the entire battery. The conditions being such as they are in regard to methods of construction and formation, I am doubtful whether any standardization is desirable at the present time. We may attempt, no doubt, to standardize the design of boxes or the methods of carrying the boxes, but I am afraid very little (if anything) can be done in regard to the standardization of the plates. Now we come to the very important question of maintenance agreements. This is always with us and in the past has given a good deal of trouble both to the purchaser and to the manufacturer. Perhaps, as Mr. Pearce remarked, the author is rather hard on municipalities in his remarks, but still there may be a certain

* A. M. Taylor: "Battery Economies and Battery Discharge Arrangements," *Journal I.E.E.*, 1911, vol. 47, p. 393.

amount of truth underlying what he says, and I fully support his suggestion that something should be done to come to an agreement as to how a battery-maintenance agreement should be drafted. The difference between the clauses inserted by various makers varies considerably, and it has led to a good deal of correspondence and negotiations with the purchasers. It is a matter which might easily be dealt with by a joint conference when we have a little more time to spare for the consideration of these questions. The author has not dealt with one of the most important points in connection with battery agreements. I refer to the provision of a clause which will automatically adjust the amount to be paid, based upon the price of lead at the time, when a battery has to be entirely replaced. If we install a battery when lead is £12 per ton, and the maintenance is a fixed rate based on that price, it will be seen how unfair it will be if lead happens to have attained a much higher price when the maker has to replace the battery. In equity, therefore, provision should be made for a variation in the amount paid when a considerable amount of replacements has to be done. Mr. Pearce is much better able to deal with very large batteries than I am. After all, however, perhaps the size is a matter of comparison between the capacity of the generating units and the battery. Many batteries were installed to level the tramway load. With a small tramway system there are very large variations in the load over exceedingly short periods. In my own case, for instance, the load may vary from approximately 100 kw. up to 600 or 700 kw. in the course of 20 or 30 seconds. Under such conditions some method of equalizing the load on the generating plant is very desirable, because it will enable the plant to be run more efficiently. It was more essential 10 or 15 years ago when tramway systems were first started than it is to-day, by reason of the fact that most of us now run a mixed system of lighting, tramways, and power, from common generating plant, and a variation of 400 or 500 kw. on, say, a 3,000 or 5,000 kw. steam-turbine set is not very serious, but it was a matter of some concern when special plant of about 500 kw. was used for the purpose. The demand for a battery for tramway purposes is not really so essential to-day as it was previously. It must not be thought, however, from these remarks that I do not agree with the use of large batteries. They are undoubtedly a source of great security. In my own case there have been a number of instances where, by reason of having the battery at our instant disposal, it has been possible to keep the supply going when otherwise it would certainly have failed. To have such a reservoir always to draw on is of immense benefit. The only other point I want to mention is the question of booster or regulator control. The first battery that I had to deal with was used solely for lighting purposes and had multiple-contact regulating switches with charge and discharge bars. When a very much larger battery was put in we decided to adopt booster control, and on the whole this has been very successful. So far as the lighting and power system is concerned I think we are bound to have hand-regulated boosters. It is far more difficult to obtain satisfactory automatic egulation in connection with a lighting and power system than it is in connection with a tramway system where the demands vary considerably from moment to moment. Hand-regulated battery boosters for lighting and power purposes are the only kind used to any extent in this country. The author remarks that regulating switches are taking their places to a very large extent in the States, but I have been trying to picture in my mind one of those regulating switches which is going to deal with the large battery mentioned having an output of about 80,000 amperes for 14 minutes. If we try to imagine connections for 80,000 amperes going to a multiple-contact regulating switch it seems a big proposition. If such a switch has been designed and used, an illustration would be of very great interest to us.

**Mr. W. A. Barnes:** In his introductory remarks the author gives a list of "many obstructing factors" to the progress in developing large batteries. It is interesting to note that he does not use the words "unreasonable prejudice" instead of "irreconcilable prejudice," for it cannot be denied that there is a large amount of prejudice amongst engineers against the use of batteries, though this is not so great amongst electrical as amongst mechanical engineers. This takes its rise chiefly from the fact that there is nothing about a battery which makes the slightest appeal to a mechanical mind. It is something messy and mysterious, belonging more properly to the chemist, and is looked upon more or less as a necessary evil in the cases where it has to be used. The "obstructing factors": (*f*) misconceptions about batteries, their functions, etc., (*g*) lack of technical supervision over battery operators, and (*i*) want of appreciation of the possibilities obtainable with batteries, should come under the general heading of (*e*) "inadequate training of engineers," but it is not so much "inadequate training" as lack of highly expert knowledge required to run a battery successfully, because the battery may be said to be the chronic invalid of the electrical world, requiring the constant attendance of the family physician. It is the only part of a power-station equipment which is generally maintained by the contractors, and hence we get another source of prejudice, "battery agreements." On page 502 the author puts forward a plea for a standard maintenance agreement, and everyone who has to deal with batteries will agree with him on this point. The want of a standard agreement is badly felt, and the author's suggestion that one should be drawn up with the approval of the Institution is a very valuable one and should be acted upon. The author, however, misses one point when he states that the modified agreement contains "the principle of the original, the interpretation of the engineer and the phraseology of the town clerk." He ought also to include "and the censorship of the contractor's solicitor." The battery to be aimed at, however, is one which can be handed over by the contractors to the users as a going concern, and one which will require no more maintenance than can be given by the users' staff, thus eliminating battery agreements. It should be so designed that the danger of damage due to short-circuits, overcharging, and undercharging, would be greatly reduced, thus greatly increasing the battery's sphere of usefulness, especially

on rapidly varying loads. I should like to ask the author whether the new type of cell "Ironclad-Exide" has been adopted for large batteries, as in the smaller sizes this type of battery seems capable of standing very much rougher usage than the ordinary type, and it would probably mean a great deal to the advancement of large batteries if this type of cell could be adopted, especially on traction plant. On page 503 the author mentions the batteries in connection with the 1,200-volt system of direct-current electrification of the Lancashire and Yorkshire Railway, and, although no figures are yet available, the operation and the methods adopted to give efficient insulation have been very successful and no trouble has been experienced due to leakage, even at the high-voltage end, though one of the batteries is situated practically underground in a humid atmosphere. In cases where batteries are used in connection with rotary converters and reversible boosters, it would appear that closer consultation should take place between the makers of the rotary converters and the makers of the battery-booster plant, in order that the characteristics of the two may be more closely allied and better and more efficient results obtained from the plant. Has the author any further information to give on the use of cadmium in cell testing ?

**Mr. T. M. Purvis :** To my mind the main appeal in the paper is the proposal *re* standardization. If people who draw up specifications understood the difficulties which manufacturers are put to in trying to meet their requirements, specifications would be largely simplified and we should then be on the high road to standardization. The greatest trouble is, as the author points o[ut] that the makers are handicapped in having to meet s[pecifi]cations which are completely out of date in many [impor]tant details. The author asks for a standard. [The m]odel which he gives on pages 500 and 501 is rather [contra]dictory to what he says on page 496. Among item[s] classified as open to standardization he gives, for [exam]ple, containers, yet in line 13 of the schedule he [says] that the type of box be specified, namely, if so[lid] specify straight, or skew dovetailed if preferred. T[his] such small points of manufacture to the fancy [of the] ient is hardly standardization, as I do not think [there] are many battery makers who manufacture both of dovetail, therefore the method of fixing the [plates] together should be the standard adopted by the [manufa]cturer in question. Coming to the details of bat[tery] design, the author mentions sunlight and its ef[fects] upon the plates of the batteries. Intense sunlight u[ndou]btedly has detrimental effects on the plates, caus[ing] disintegrating action on the positive plates, b[ut] experience in this country is that such action is [negli]gible. The greatest effects are due to the atmos[phere] causing evaporation, and if impurities are pr[esent] their activity for mischief is highly increased w[ith] high temperature. Evaporation is, I might menti[on] increased by the use of wooden separators, espe[cially] where these are supported by wooden dowels [pro]jecting above the level of the acid, moisture rising to th[e ends] of the dowels and evaporating in proportion to the [dry]ness of the air. One speaker approved the conditions of the maintenance agreement. The conditions mentioned by the author hardly vary in the slightest degree from actual conditions of standard maintenance agreements. In regard to the same speaker's complaint of the trouble batteries give, due to the cells being damaged by overcharging or overdischarging, a battery is designed to give a certain output at certain rates and cannot be expected to work satisfactorily if users try to get from it more than it is meant to give. On the contrary, is sufficient attention paid to the readings of specific gravity and voltage of the various cells by the users ? Cells do not break down unexpectedly, and ground exists for assuming that the range of specific gravity in a cell will correspond at least with what it did on the last discharge at a similar rate. The hydrometer is a reliable means of ascertaining, not only what amount of work the cell has already done, but also, what is more important, the additional amount it may be expected to do, and therefore if records are properly tabulated and looked to, one should always be able to reckon on the remaining capacity of the battery at any period of its discharge. The trouble in taking specific gravity readings is largely due to the very bad divisions on the hydrometer. With better divisions much more accurate readings could be taken much more readily. At present all readings are taken on the surface of the electrolyte, and the meniscus formed by surface tension tends to prevent a true reading. A hydrometer which reads about 1½ and 2 inches above the level of the acid by means of a float is on the market and has been adopted, I understand, by some Government Departments. This method makes the reading of specific gravity very much easier, and a duty which would be more readily fulfilled by users. In regard to stand-by batteries, a plate embodying the virtues of the Planté and Faure types would seem to meet the case. Such a plate has been perfected by one of the battery makers and has given very successful results for a number of years. It is free from chemical impurities, the capacity of the plate does not decrease and, where proper treatment is given, cases have been known of an increase in capacity and of positives outlasting negatives. It would be interesting to have the author's opinion on the effect of temperature on alkali batteries. The capacity of lead plates is only slightly reduced at lower temperatures. Alkali batteries, however, lose practically all activity. For instance, at 40° F. the capacity of a lead plate is only about 10 per cent lower than at 60° F. ; whereas at high temperatures lead positive plates slightly deteriorate, though their capacity is increased, but with alkali cells such high temperatures are fatal.

**Mr. L. Broekman :** The prejudice against batteries to which Mr. Barnes referred is the outcome of past experience—personal experience in some instances, hearsay in others. Hearsay is by far the worse of the two, and I get a good deal of this. To find a reason for it one has to go back to olden times, 15 or 20 years ago, when batteries were installed which were entirely inadequate and had no effective stand-by value. The miscalculations and mishaps of that time have had rather an unsettling effect. Engineers in highly responsible positions now were then among the juniors, and as such were probably associated with the battery management. Now, whether at that time the real

grievance did lie with the battery or with its guardians, can only be conjectured, but, recollecting my own frailties at that tender and impressionable age, I am inclined to back the battery. Certain it is that similar early disappointments in life have haunted the memory of many of our big men. Their work, in many cases and for a number of years, has been connected with stations where batteries are not supposed to be necessary, rightly or wrongly; they have had no need, therefore, to concern themselves specially with the marked progress made in accumulator manufacture. That should not, however, lead to the conclusion that makers have been asleep. Very far from it. Battery maintenance agreements are occasionally made the target of adverse criticism, but what can there be more comprehensive than the responsibilities undertaken by the makers under these insurance contracts? The utmost care is taken by them in the selection of materials to exclude every trace of impurities; tests, checks and cross-checks at every step during the process of manufacture, making sure that every part is perfect according to the latest knowledge; and then handing over the finished product to be operated with a wide margin for individual discretion, and under conditions which, in the nature of things, cannot be definitely stated. Emergency service always is writ large, and emergency service is the "hidden hand." No one can tell when, or how often, or to what tune it may be called for, but so much is certain, that whatever it amounts to the battery has to stand up to it, and the battery maker is responsible. The employment as battery attendants of men who have been through the shops of the makers is undoubtedly an excellent plan. I only wish that this were common practice in all stations where batteries are largely used. From long experience with accumulators I know that the modern storage battery has nothing to fear from the enthusiasm of its advocates, provided that the installation is suitably planned in the first place, that the initial charge and setting to work is properly carried out, and that the plant is given appropriate treatment by the users.

**Mr. E. Thomas:** The paper and discussion stand out in my mind for the author's championship of the end-cell switch, and Mr. Pearce's announcement of his conversion to the same method of control. It is of interest to remember that lead saving as used with these switches was in the first place an English invention, but English engineers failed to appreciate its advantages until it was introduced to us years later by the Germans, when they enthusiastically accepted it. It would appear that English engineers were a good bit behind German and American engineers in the use of large batteries, and when they waked up to the advantages some of those who favoured end-cell switches would accept none but those of German make. Indeed in one case a specification was issued calling for a current density at the brush contacts of 100 amperes per square inch English makers were informed that they must comply with this, but I believe that German switches were installed in which the current density was more nearly 400 amperes per square inch. This attitude was not adopted by all engineers, however, and at the present day English switches are fully recognized, and orders are only held up by the war for switches of 10,000 amperes' capacity. The English gear is probably a sounder engineering job than the German and has all its refinements. Moreover, it has been standardized in a form which better meets in one piece of apparatus the very varying conditions of approach of the heavy copper connections. End-cell switches of small or large size lend themselves with extraordinary ease to the use of all sorts of automatic and semi-automatic devices. At present many batteries are in use in substations with end-cell switches and automatic regulators. During the night the substations are locked up and all running machinery and labour are stopped, while the automatic regulator controls the voltage during the night. It is interesting to note that apparently the author feels doubtful of the future of large batteries in this country. Mr. Pearce, however, after extended experience, pronounces definitely in favour of combined load-levelling and emergency use. In any case it seems likely that there is room for a very extended use in the future of the moderately large battery with end-cell switches and automatic operation. The end-cell switch, moreover, lends itself not only to automatic control of discharge, but probably also to control of charge. End-cell control has a bad name in some quarters, but I think accumulator experts consider that with intelligent charging the troubles which have been found disappear. Probably this will be got over by better instruction to the attendants and better record-keeping by them, but it would also appear that the end-cell switch may be arranged automatically to charge the battery as well as to discharge it, and may do something towards eliminating this defect. The paper covers a great deal of ground and mentions most of the typical details. One, however, seems to be omitted. Wherever booster control, as distinct from end-cell control, is used, and when the battery is intended to deal with emergency loads, a switch is necessary to cut out the boosters when such emergencies arise. In the early days this was done by short-circuiting the booster while simultaneously cutting out its field. This was a very drastic course and nowadays means exist, and have been in use for very considerable periods, for cutting out the booster without short-circuiting it, but also without interrupting the supply from the battery. In the matter of end-cell regulation we let the Germans get ahead of us, but we have now caught them up. In methods of booster control we probably were never behind them, and the installation at Bradford, with all heavy switches in separate cubicles, remote controlled, and with the provision of automatic control for conditions of emergency, is probably as complete as, or better than, any installation abroad.

**Mr. D. S. Paxton:** A previous speaker has inferred that the alkaline battery becomes inert at a temperature of 40° F., but this does not agree with observed facts. The question is hardly relevant to the subject under discussion, as the alkaline battery is employed almost solely for traction purposes, where mechanical strength is the main consideration, and not in the form of "large batteries for power purposes," but as the point has been raised, reference may perhaps be made to experience

with electric vehicles operated by alkaline batteries. After standing all night under extreme winter weather conditions such batteries have been found to be far from inert, and the vehicles have run considerable distances without initial boosting. What actually happens is that the internal resistance is increased by the low temperature and the effective voltage is naturally reduced, so that there is a lower power output available. The same applies to lead batteries in a certain degree. Indeed, on page 495 the author mentions that at low temperatures the mean voltage on discharge is lower and the mean voltage on charge higher. That is to say, the internal resistance is increased at the lower temperatures and the efficiency consequently decreased. On page 498, the author refers to the depth of space below the plates. Some years ago, as a result presumably of short-circuits between plates, battery manufacturers introduced the practice of providing a considerable space for the accumulation of sediment below the plates. As the author points out, it is important that this space should not be too deep, otherwise the heavy gravity acid settles at the bottom. I remember a case which occurred before this point was quite appreciated. One of the early batteries, provided with a large clearance for the safe deposit of lost active material, refused to maintain its correct gravity, and in spite of charging night and day for about 4 days in the vain endeavour to raise the gravity to the correct value, the gravity steadily fell instead of rising, owing to the fact that the acid gradually settled at the bottom. This tendency is perhaps responsible for more trouble than is generally realized, and the point is obviously one of considerable importance.

**Mr. G. S. Wallace:** I see nothing in this paper on the subject of receptacles for distilled water. I cannot say that we can look upon a telephone exchange battery as a very large battery, but we have a certain amount of difficulty with regard to the distilled water question. We have got over it to some extent with a large battery that we have recently installed by arranging for a trough fitted with a tap, but one little difficulty we experienced was in getting the carboys of distilled water lifted into the trough. These carboys usually come packed with hay or straw, and a lot of dirt and dust gets into the battery room. I should like to have the author's opinion as to the best way of dealing with this distilled water problem. In the battery I have in mind there is about 4 feet from the top of each cell to the ground.

**Mr. H. C. Sabine:** Where large batteries are above the ground it is very useful to have a pipe fitted for conveying the deposit to the ground. One generally handles the mud in the battery room with special apparatus, and it is often inconvenient to lower the mud in barrels. When the battery is on the ground floor that point does not arise. If one has pure acid and materials at the start and uses distilled or reasonably pure water—distilled for preference—it is not necessary to renew the acid very often. The author suggests an ordinary split-cable insulator; the surface of this is very small, and between the two halves dust collects which, being loaded with acid, reduces the insulation. An insulator with a large surface is preferable. I would impress upon engineers that gangway platforms should be provided. It is very awkward to inspect deep cells without them. The author gives a long list of accessories, including a chemical testing set. I do not think that the ordinary battery attendant is capable of carrying out these tests satisfactorily; this should be left to the manufacturers. Some of the other things are most useful, but I do not like apparatus for repairing plates. Some battery attendants are much inclined to cut out plates which would be better left in the battery. Stillage for large cells would, I think, necessitate a large amount of labour in erecting a battery. It is necessary to have a very large number of bearing points dead level, and I have never seen a battery-room floor left in this state for the battery erectors, so that erection would be long and tedious. When one has a long cell—not a cell with a plate about a foot square but a long cell with a deep plate—4 feet is rather small for a gangway when repair work is being carried out, especially if a trolley milking booster is used. Within reason one cannot have too much room. It is much better for everybody concerned. One trouble with plates having long lugs is that one gets such varying readings of the specific gravity before and after topping the cells with water, and the battery attendant is inclined to think that there is something wrong. I do not quite see how the repairs of the high-tension end are going to be carried out and the battery still kept in service, which on railway work is essential. The author might deal with that point. For alternating-current systems I think it would be quite a good scheme to use a battery and a rotary converter with a boosting field. This could be used as an emergency alternating-current plant or for dealing with the peak load. It is not necessary to have a booster, as a suitably designed rotary converter will give sufficient range for charging or discharging. It is vexatious to engineers and causes a lot of inconvenience to have to take a battery off the busbars for repairs. Many large batteries have practically never been taken off the busbars except for a few minutes or perhaps an hour or so at night or in the early morning. It gives the manufacturer a little more trouble, but it is much more satisfactory. Very often engineers calculate on the average busbar voltage and not on the maximum voltage in deciding upon the number of cells for a peak battery. I think it is better to deal with the maximum busbar voltage, especially when the battery is to be used largely for peak work. Many speakers have made remarks on maintenance agreements which I think are more imaginary than real. In the ordinary way the battery maker carries out his obligations. Where they do not they ought to be made to carry out the necessary repairs. If they carry out their obligations in a fair way one does not have any trouble, and where there is a maintenance agreement I do not find any friction arises, but where there is no maintenance agreement and the engineer has to ask his Committee for a complete renewal of the battery, trouble begins. If the battery is under maintenance I find that the manufacturer automatically puts the repairs in hand, sometimes without any correspondence and often before the engineer appreciates

that there is anything wrong with the battery. With regard to Mr. Purvis's remarks on estimating the discharge by noting the fall in the specific gravity, it is important that the battery should always discharge at the same average rate every day. The capacity in ampere-hours varies with the rate of discharge. Assuming that the percentage of ampere-hours discharged at the 5-hour rate is taken as 100, at the 10-hour rate one gets 120 per cent and at the 1-hour rate about 60 per cent. As the drop in specific gravity is nearly proportional to the number of ampere-hours discharged, the drop at the 1-hour rate is approximately half the drop at the 10-hour rate. Unless the average rate of discharge is known it is difficult to calculate the state of discharge of the battery from the drop in specific gravity.

**Mr. E. C. McKinnon** (*in reply*): Those contributors to the discussion who expressed pessimistic views of the utility of batteries on the ground of costs, should observe Mr. Pearce's opinion that "a peak load battery taken even at the 1-hour rate effects a saving in capital charges in comparison with steam plant, and is also capable of fulfilling to a very large degree the functions of a purely emergency battery." This should be read in conjunction with Mr. Watson's view that he regards large batteries as a "source of great security." Another unqualified conclusion by Mr. Pearce is that "there is an increase in efficiency to be gained by the end-cell regulation method of control," resulting in more efficient operation. Public supply engineers appear to rely on a continuance of the "conditions which obtain to-day." Mr. Pearce doubts the possibility of purely stand-by batteries being adopted in this country on lines similar to the practice in the States, but as the country's industries and illumination become more and more electrically controlled, it is inconceivable that supply companies and municipalities will continue to be immune from heavy penalties for paralysing breakdowns, and gas, at best, is a poor stand-by. Faure plates of any type will not maintain their maximum possible capacity indefinitely on open circuit, but they do maintain it better than Planté plates. Faure plates will maintain their commercial rating for at least 2 weeks without a freshening charge. There is a recognized margin in the actual capacity of a battery above its commercial rating.

Mr. S. J. Watson has indicated some of the difficulties at present in the way of standardization, but they are far from insuperable, and Government Departments have given a good lead in this respect, including dimensions of plates. An adjustment in the rate of maintenance premiums proportional to the market price of lead is already an accomplished fact.

Mr. Barnes misses the point when suggesting that the ideal battery is one which will require no more maintenance than can be given by the user's staff. Surely the obverse would be that the ideal staff of a large electric power station should include at lease one member who is competent to operate a storage battery correctly, and will do so without having to be constantly reminded by the makers that neglect and inattention must necessarily lead to an unsatisfactory and costly conclusion. The "Ironclad Exide" battery has been employed for large batteries for specific purposes, but it is not designed for stationary work.

Mr. Purvis asked for my opinion on the effect of temperature on alkali batteries, and then gave facts which, if correct, speak for themselves, but were challenged later by Mr. Paxton.

Mr. Eustace Thomas has formed a totally wrong impression in noting that I appear doubtful of the future of large batteries in this country. I have no doubt at all of the future of large batteries, but have gone to pains to indicate the factors which may affect the uses to which batteries will be put.

Various omissions were referred to by different speakers, such as emergency switches for cutting out a booster when necessary, a milking booster, acid filters, etc. I agree that these might very well have been included, but the paper was already deemed too extensive.

Mr. Wallace should stipulate for stone jars, wicker-cased, as a satisfactory means of transporting distilled water.

Mr. Sabine's remarks were practical and pertinent. Repairs to high-tension batteries on railway work certainly offer difficulties, but these are satisfactorily overcome according to the local conditions to be met.

## South Midland Centre, at Birmingham, 17 April, 1918.

**Mr. F. Forrest**: The author does not bring to light anything very new, but he sets out with great clearness points which should be thoroughly well understood by all users of storage batteries. Large batteries, whether used for stand-by purposes or for more general use, are likely to be installed in stations situated in crowded areas. Owing to the great volume of acid-laden air which would be discharged from battery rooms, it is necessary to take steps to prevent this being a nuisance to surrounding property owners; and one way of rendering the discharged air less objectionable is to pass it through acid filters or "acid neutralizers." These acid neutralizers consist of a number of finely perforated lead screens through which the acid-laden air passes and down which water flows slowly and clears the air of the acid in suspension. Many of these acid neutralizers have been in use for years in the States, but very few have been installed in this country. Two are erected in one of the sub-stations in Birmingham and have proved very satisfactory, these having been built to designs kindly supplied by the Chief Engineer of the New York Edison Company. As only distilled water should be used for make-up purposes, an efficient distiller should form part of a large battery equipment and must be capable of easily supplying the requirements of the battery during the warmest weather. A very satisfactory arrangement is to keep the distiller working constantly and to store the distilled water in wooden lead-lined tanks mounted some distance above the top of the cells

so that the water can be drawn off by gravity. If it is necessary to transport the distilled water from one station to another, this should be done in ordinary glass carboys. Before any of the distilled water is used, samples of it should be drawn off and tested either with the Dionic water tester or by the nitrate-of-silver test. A portable milking booster is also a necessary accessory, and a very good form to adopt is one which combines on a single carriage the small motor-generator together with all necessary switchgear and instruments. A number of concentric plugs should be arranged round the battery room so that the polarity cannot be altered, and as far as possible the machine should be rendered fool-proof. The whole equipment is mounted on rubber-tyred wheels and arranged to turn into any of the gangways with ease. The watt-hour efficiency of a battery is so difficult to determine accurately that I venture to suggest it should be no longer included in battery specifications. Ampere-hour efficiency is really all that one wants to know and, as it can be obtained without any loophole for error, it should be the standard upon which to frame guarantees. To obtain the watt-hour efficiency it is necessary to recharge a battery to exactly the same condition in which it was before the discharge test commenced, and it is almost an impossibility for even an expert to state when a battery is in precisely the same condition as regards both its voltage and specific gravity. A short period of undercharging would improve the apparent efficiency and upset the accuracy of the test. The usual type of hydrometer in use is a rather unsatisfactory means for testing the condition of large batteries, and I would ask the author whether he is acquainted with any other forms of hydrometers having a larger and better-defined scale than the small things one is compelled to use at present. I believe the author will agree with me that to work to specific gravity alone is one of the most satisfactory ways of operating a battery, and it is therefore very essential that the hydrometers used should be of the best possible type. With regard to the control of large batteries, we have in use in Birmingham a number of regulating switches generally of the type illustrated in the paper, but, unfortunately, these were obtained from abroad. Each half-battery in connection with the three-wire system is controlled by one of these switches, which is connected between the neutral point and the battery so that there is a minimum voltage to earth on the switch. This I consider to be a very important point to watch in connection with either boosters or cell regulating-switches. The working results with large and small batteries have demonstrated that the trouble experienced is inversely proportional to the size, and those people who have connected solidly to their busbars a large battery appreciate its value, especially in times of emergency. Unfortunately, in this country small batteries have been the rule in the past and their working results have left much to be desired. It is to be hoped that this paper will help to remove the prejudice which undoubtedly exists against batteries in this country.

**Mr. G. Rogers:** This paper is calculated to disarm a great deal of the unjust and unreasonable prejudice which has for so long dogged the storage battery in its relation to power supplies. The author is rather severe upon the engineers who have been responsible for the drafting of battery specifications, but it must be remembered that the educational facilities for large battery work have been non-existent. The subject has been only a side issue, and any knowledge gained has been due to individual effort on the part of engineers to master the chemical and engineering problems peculiar to storage batteries. Needless to say, very few (apart from those directly interested in the business) have taken the trouble to do this. With regard to the author's remarks upon the obstructing factors which have caused delay in the progress of battery installations, I should like to draw attention to another factor—the failure of battery makers to meet their responsibilities under maintenance contracts. An unhealthy battery peculiarly lends itself to variable diagnosis, and the trouble is invariably laid at the door of the owner of the plant. The battery makers neglect to watch the daily records, which they require sent to them throughout the life of the battery, and, when trouble arises, delay ensues in carrying out the necessary repairs. The terms of the maintenance contracts, and the representations of the manufacturers to their customers as to the treatment of their battery plant, have largely been responsible for the idea that batteries have to be treated as invalids. The danger is that ultimately the owner begins to regard them as chronic invalids, and becomes dissatisfied with them. The maintenance department should be in constant touch with all records, and be regular in the periodical inspections; the instructions for the working of the battery should also be stated as simply as possible. Any faults in the battery will then be discovered immediately and the remedy applied. It is very interesting to note that an English engineering firm is now prepared to supply large switches for use with regulating cells. From the diagram it would appear that these switches bear a great resemblance to the switches supplied by Messrs. Siemens of Berlin. One feature, lacking in the Siemens switch, is very important and useful, viz. the switch is capable of being operated and cells cut in when the load is considerably more than the full rated load of the switch. There seems to be a note of apprehension in the author's view of the future of large batteries as applied to the electrical industry. I am inclined to think that in this country the developments of electrical supply, which are now being seriously considered, are likely to cause a decreasing demand for batteries. It would seem that the distribution of power for lighting and power purposes in the future will largely be by means of three-phase four-wire networks. It must be remembered that cheapness of supply will be the dominating factor in this development, and reliability and continuity of service will have to be provided by means of duplicate supply. The losses incurred in the use of converting plant and battery auxiliaries will therefore be avoided. Even the country-house battery plant is likely to be superseded sooner or later by the transformer. There is, however, likely to be a demand for buffer batteries for use with traction systems, if direct-current drive

is eventually adopted for the electrification of suburban and main-line railway systems.

**Mr. W. Wilson:** The author has not included any references to the development of the accumulator, but there seems abundant evidence in the paper that considerable improvements have been effected within recent years. The author mentions cases in which the whole discharge was complete in 14, and even in 10 minutes, requiring a high discharge-rate that we once used to consider would have seriously damaged the plates. According to the old theory, such high current-densities resulted in a concentration of chemical action at the surface of the pellets, causing them to expand and stretch the grids, so that upon recharge the component parts were loosened and the way was prepared for disintegration as well as distortion. I was particularly interested to learn, from page 504, that the Faure type of plate is the more durable under stand-by conditions, as it is the type that one would have thought to be more sensitive to abnormal treatment. The high cost of the battery, being approximately equal to that of boilers, engines, and generators for the same output, was also a drawback to its use, if its depreciation was to be high. I should be interested to know the value of the worn-out plates, as compared with the new. This should form an important offset to the cost of renewal. On page 494, the author advocates a floor gradually sloping from end to end. Is this to obviate the drainage crossing the alley-ways, as otherwise the shorter movement from side to side would seem preferable? With regard to the light fittings in use for battery rooms, it is surprising how durable ordinary holders and switches are in such an atmosphere. A marine engineer is always prepared to find that the metal in a switch or holder has been converted into a mass of verdigris, even in such protected places as the saloons, and it might have been expected that the effects of acid, even in the case of porcelain-clad fittings, would have been as marked as in the case of salt. I once went to the trouble of having the watertight type of fitting installed in a battery-room for this reason, but the precaution seems to have been unnecessary. The reference to Colonial practice, and to the "nursing" of the Colonial markets by foreign manufacturers, attracted my attention. As a former occupant of one of the Overseas Dominions I have always attributed foreign influence there more to inaction on the part of the British firms than to any abnormal procedure on the part of outsiders. Sydney and Melbourne both have large battery installations, with end-cell regulation, controlled by very good switchgear, resembling the arrangement shown on page 508. In New Zealand, batteries are also in fairly general use, with booster regulation. The commercial practicability of using stand-by batteries for large alternating-current stations seemed to me to be one of the most important advances touched upon by the author. It is unfortunately necessary with many hydro-electric schemes to provide a stand-by of some sort, with a capacity up to about one-third of that of the hydraulic supply. Using heat engines for this purpose, the advantages of the hydro-electric installation are partly cancelled; and it usually takes at least 15 to 60 minutes for the emergency power to become available. If such a method as that adapted by the Boston Edison Company were employed, much better results should be possible, and an important step would have been taken towards counteracting the awful mortality that still exists among extra-high-tension insulators.

**Dr. C. C. Garrard:** This paper embodies a very earnest plea for standardization in the battery trade. In this the battery manufacturers fall into line with all other branches of the electrical industry, it being recognized that more standardization is absolutely necessary if the increased productivity which is essential is to be attained. The authority which has been set up in this country for engineering standardization is the British Engineering Standards Association, but the initiative for any standardization work has to come from the trade itself. The first essential is that the various manufacturers should look at the matter from a broad-minded point of view and express willingness to pool their knowledge to a certain extent. Of course it is not to be expected that all trade secrets will be placed on the table, but there is no doubt a vast amount of knowledge and experience which could be made available and upon which the proposed standardization could be built. I quite agree that such standards have to be revised periodically. The ideal to be aimed at is, however, that every trade shall have its living standards. These should be in a continuous state of growth and represent at any time the accepted standard of achievement. Not only would this give enormous help in production and facilitate business, but it would be likewise the best guarantee of continued progress and improvement.

**Mr. E. C. McKinnon** (*in reply*): Mr. Forrest described in detail the acid filters and distilling plant alluded to in the paper. A portable booster is less satisfactory than a stationary one from which conductors are carried to terminals fixed in suitable positions in the battery room. The booster, consequently, is never brought into contact with any acid-laden air. I agree with Mr. Forrest that the watt-hour efficiency of a battery is an uncertain quantity. I am not cognizant of the small hydrometers which he uses, but accurate and substantial instruments are on the market. It is difficult to work a battery by specific gravity alone. Various speakers have raised this point, but owing to the varying height of the electrolyte, the effect of temperature and gas on the specific gravity, and the tendency to stratify in very deep containers, upsetting factors are introduced.

Mr. Rogers submitted that battery makers should stand over the battery to see that the conditions of maintenance contract were in force and were observed. In no other form of assurance is this onus laid on the party who accepts all the risks. All battery-maintenance agreements stipulate that the user shall provide an efficient battery attendant who shall carry out the working instructions. If the battery makers upheld their right under the agreement not to make good any damage caused by improper usage (as a matter of fact in almost every case this damage is borne by them), the status of the battery attendant would

be improved and he would be less of a station handyman.

Mr. Rogers put forward duplicate supply as the basis of reliability for continuity of service, but an alternative source of supply would often give still better security.

Mr. Wilson alluded to the necessity of providing a stand-by of some sort in hydro-electric schemes up to about one-third that of the hydraulic supply, despite which a shut-down of at least 15 to 60 minutes is accepted as usual. A battery would eliminate all such disorganization. The market value of scrap lead from batteries is about 25 per cent of the market price of new lead.

It was gratifying to receive such substantial support to my plea for standardization, and Dr. Garrard gave admirable reasons for raising the ideal above the jealousies of competition.

# ANNUAL CONVERSAZIONE, 1919.

The first Conversazione of the Institution since the outbreak of War in 1914 was held on Wednesday, 25th June, 1919, at the Natural History Museum, South Kensington, by permission of the trustees of the Museum. The guests, who numbered about 1,300, were received by the President, Mr. C. H. Wordingham, C.B.E., and Mrs. Wordingham. In a speech of welcome to the members of the Institution who have served in H.M. Forces during the war the President said :

" Ladies and Gentlemen,

" On this joyful occasion our dominant feeling must be one of thankfulness. Primarily to God for having brought this nation through this crisis in its history in triumph shared with its noble Allies, and for the peace which is the immediate consequence of that triumph. Thankfulness also for the bringing back in safety of those who are with us to-night and whom we are assembled to welcome and to honour.

" Secondarily are our hearts thankful to those whom He has used as His instruments in the persons of those who have fought, and many of whom have died, to secure that triumph and that peace.

" It is no hypocrisy to say that we have not won this War in our own strength. Although we were fully warned we were utterly unprepared. We had but a handful, as armies now go, of trained men, a navy which we are assured on the highest authority was deficient in certain vital respects, we had practically no hospital ships or ambulance trains, no adequate supply of suitable armament, and we were matched against a nation which had spent 40 years in steady preparation, which had sucked the brains of every other nation for ideas and inventions, which stopped at no degradation in the practice of war, using the foulest methods of the vitriol thrower and murderer, and yet we won. We may say it was due to this man or that, to the sailor or the engineer, to our money or to our cleverness, but if we are honest we shall say that we owe it to God's goodness and mercy.

" It is true that many of those who stayed at home have been just as indispensable as those who have fought and they have done their utmost to contribute to the result of the nation's effort, but, after all, nothing can come up to the services of those in the field. They have worked as hard as any for longer hours than most and, over and above all, they have faced the foe at close quarters. It was no ordinary foe, but a foe without a spark of honour, chivalry, or human feeling, a foe full of bluster when victorious with overwhelming odds on his side, and a craven and snivelling coward when beaten. A foe whom, though he sign a treaty of peace, we must ever be alert to watch lest at the last he sting us like an adder.

" We as engineers are specially proud of our men, because, while a large proportion entered the ranks, the greater number subsequently earned commissions. We are proud of their merit, but especially proud because the facts show that an engineer's training fits him for administrative work and the command of men.

" The Council considered many ways of welcoming back those whom we desired to honour, but we felt that nothing could be better than this Conversazione because it gives all members the opportunity of talking to one another personally. It is five years since the last Conversazione ; few of us have escaped bitter loss in that time and the thoughts of many of us will be with those no longer with us. We shall not diminish the heartiness of our welcome to those among us to-night because we do not forget those who have not returned. Let those who are bereaved join heartily with the others in welcoming home the men who have been spared to those who love them. To one and all, whether they come from land or sea or air, I extend the warmest, heartiest, and sincerest welcome from every member of this Institution."

# ANNUAL DINNER, 1919.

The Annual Dinner of the Institution was held on Thursday, 26th June, 1919, at the Connaught Rooms, Great Queen Street, W.C. The President, Mr. C. H. Wordingham, C.B.E., presided over a gathering numbering about 300 persons. Among those present were: Sir Evan Jones, Bart., M.P., D.L., J.P. (*Controller, Coal Mines Department, Board of Trade*), Sir George H. Makins, G.C.M.G., C.B. (*President, Royal College of Surgeons of England*), Lieut.-Gen. Sir W. T. Furse, K.C.B., D.S.O. (*Master General of Ordnance, War Office*), Sir Frank Heath, K.C.B. (*Secretary, Department of Industrial and Scientific Research*), Sir H. Rolleston, K.C.B., M.D. (*President, Royal Society of Medicine*), Colonel Sir T. Holdich, K.C.M.G., K.C.I.E., C.B. (*President, Royal Geographical Society*), Rear-Admiral Giuseppe de Lorenzo, K.C.M.G. (*Italian Navy*), Sir H. P. Burt, K.C.I.E., C.B.E. (*Government Director of Indian Railways, India Office*), Lieut.-Col. Sir John Marshall, K.B.E., Colonel Sir A. M. Ogilvie, K.B.E., C.B., V.D. (*Second Secretary, Post Office*), Sir Charles Bright, F.R.S.E., Sir Vincent Evans, F.S.A., The Hon. J. M. G. Biddulph, Colonel R. E. Crompton, C.B. (*Past President*), Rear-Admiral F. L. Field, C.B. (*Director of Torpedoes and Mining*), Brig.-Gen. C. P. Martel, C.B. (*Chief Superintendent, Ordnance Factories, Woolwich Arsenal*), Brig.-Gen. Brooke-Popham, C.M.G., D.S.O., R.A.F., Colonel H. C. Sparks, C.M.G., D.S.O., M.C. (*Member of Council*), Lieut.-Col. A. D. Warrington-Morris, C.M.G., O.B.E., Mr. L. B. Atkinson (*Member of Council*), Dr. G. B. Batten, M.D. (*President, Röntgen Society*), Mr. H. Booth, O.B.E. (*Board of Trade*), Mr. H. F. Carlill (*Controller, Industrial Power and Transport Department, Board of Trade*), Mr. A. Carpmael, (*Hon. Solicitor*), Mr. R. A. Chattock (*Vice-President*), Mr. H. W. Clothier (*Past Chairman, North-Eastern Territorial Centre*), Mr. F. W. Crawter (*Member of Council*), Mr. D. N. Dunlop (*Member of Council*), Mr. A. G. Ellis (*Hon. Secretary, North-Western Centre*), Mr. J. Gray, Mr. A. B. Gridley, Mr. W. B. Hardy, M.A. (*Secretary, Royal Society*), Mr. H. H. Harrison (*Member of Council*), Mr. J. S. Highfield (*Member of Council*), Mr. H. M. Hobart (*American Engineering Standards Committee Delegate*), Dr. E. Hopkinson, M.P. (*President, Institution of Mechanical Engineers*), Mr. E. M. Hughman (*Hon. Secretary, Calcutta Local Centre*), Mr. G. H. Hume (*London County Council*), Mr. G. W. Humphreys (*Chief Engineer, London County Council*), Mr. J. E. Kingsbury (*Hon. Treasurer*), Prof. C. H. Lees, D.Sc., F.R.S. (*President, Physical Society of London*), Dr. C. R. C. Lyster, M.R.C.S., F.R.S.M. (*President, Electro-Therapeutic Section, Royal Society of Medicine*), Mr. W. McClelland, O.B.E., Mr. S. Machin (*Chairman, London Chamber of Commerce*), Mr. C. O. Mailloux (*Past President, American Institute of Electrical Engineers*), Prof. T. Mather, F.R.S., Prof. C. E. Mendenhall (*Scientific Attaché, American Embassy*), Mr. W. M. Mordey (*Past President*), Mr. H. Mukoyama (*Imperial Japanese Navy*), Mr. J. F. Nielson (*Chairman, Scottish Territorial Centre*), Mr. W. Noble (*Engineer-in-Chief, G.P.O.*), Lieut.-Col. E. O'Brien, D.S.O., Mr. G. W. Partridge (*Vice-President*), Mr. C. C. Paterson, O.B.E. (*Member of Council*), Mr. A. H. Preece, Mr. G. Scott Ram, Mr. W. R. Rawlings (*Member of Council*), Prof. A. Schuster, D.Sc., F.R.S. (*Secretary, Royal Society*), Mr. R. T. Smith (*President-Elect*), Mr. C. P. Sparks (*Past President*), Mr. A. A. C. Swinton, F.R.S. (*Chairman of Council, Royal Society of Arts*), Mr. W. B. Woodhouse (*Vice-President*), and Mr. P. F. Rowell (*Secretary*).

The PRESIDENT gave the toasts of "His Majesty the King," and of "Her Majesty the Queen, Queen Alexandra, His Royal Highness the Prince of Wales, and other Members of the Royal Family."

Dr. C. O. MAILLOUX, in proposing the toast of "The Institution of Electrical Engineers," said: This is really one of the occasions when I may truthfully say I was taken by surprise, for as I entered the door the very disturbing information was conveyed to me that I was expected to propose a toast. Although taken by surprise, I considered it a great pleasure to say that I would do so. Sir Hamar Greenwood, who was to have proposed the toast, is a Britisher, and could not say the nice things about the Institution which I am going to say. I have known the Institution since I was a little boy, and I have always known it in terms of that greatness, of that magnitude, and of that respect which everybody in the electrical business is bound to admire and think well of. So that long before I reached the age of maturity, before I had begun my own career as an electrical engineer, I had something to look up to, namely, that I might myself some day become a member of this Institution. In the meantime we have formed an Institute of our own in the United States. I was one of the members who had an opportunity of participating in its formation, and, as the Chairman has said, I have also been honoured by being its President. I have attended many meetings of the Institution of Electrical Engineers, and not a few of its banquets, and I may say that on many occasions I have met here some of the finest and greatest men in the world, for the Institution has had on its lists names that have stood out in the science and theory and practice of electrical engineering. The term "The Institution of Electrical Engineers" has therefore a meaning to anyone connected with the art and practice of electrical engineering far greater than can be said in two or three words. As I have said, I have been here many times. I remember very well one of the great occasions, when the Institution in 1900 invited the electrical engineers of the world to come here, and I was one of the honoured guests from America. I was one of those who went on that admirable trip through-

out Great Britain—the most interesting, the most carefully prepared, and the best-conducted technical trip that has ever been made and one that has stood out ever since as a model trip which we in America sought to copy in 1904, when we invited you to come over and see us. The Englishman has shown his ability to right things. He may make mistakes, but he always recovers from them, and he always makes good. This is one of the cases where we Americans can praise you and commend you and glorify you for the great and glorious manner in which you have made good. One of the great articles written in our country during the war is entitled "The Unboasting British," and I can think of no title of glory and praise to confer upon you better than that very one. I am glad to be able to appear before you, and to say to you that we in America have to express to you our feelings of gratitude for the great share you have taken in setting the world right once again, and particularly to tell you of the great work which the Institution of Electrical Engineers, in common with the other engineering Institutions in England, has done in connection with the war. Being a member of this Institution I received its *Journal*, and a thrill went through my heart as I glanced at it each month to see the account of the work done, quietly and modestly, but most effectively, by the British, and to see the list of casualties of men who had laid down their lives in order that the world might live. Then I used to say to myself that if it does nothing else it will have accomplished enough to make it worth while to have brought our Americans to a realizing sense of what a great country Britain is and what the world owes to it, especially as it has brought us so close as it has. There is one thing which stands out in this war, namely, the great respect which has been inspired and instilled in American hearts, the great feeling of closeness, the great feeling of brotherhood that we never felt before as we feel now. I give you the toast of "The Institution of Electrical Engineers."

The PRESIDENT (Mr. C. H. Wordingham), in responding to the toast, said: It is peculiarly appropriate that this toast to which I have the privilege of responding in the name of the Institution should have been proposed by an American. We have been fighting together shoulder to shoulder in the great war from which we are just now emerging, and we have been co-operating in peaceful arts more closely than ever before, with a great branch of our own brothers of the Anglo-Saxon race. We are acting in regard to electrical matters in the closest possible unity. Our own Engineering Standards Association is affording every possible assistance in regard to the formation of the American Standards Committee which is being modelled on the lines that we have evolved for ourselves. Therefore I say it is peculiarly appropriate that this toast should have been proposed by Dr. Mailloux, one of the Past-Presidents of the American Institute, which corresponds so closely to our own in its status and position in America. Now in responding to this toast I think I may safely claim that our Institution represents the whole of the British electrical profession and industry. Our members closely approach the number of 8,000. Never before, I think, as within the last few years has there been such close co-operation between the Institution and those other organizations which have been formed to look after sectional interests. Over and over again these other Associations have met under the ægis of our Institution, and always with the happiest results. In responding therefore for the Institution I feel I may justly claim to have the honour of responding for the whole of the electrical industry and profession. I will not weary you with a list of recent activities of the Institution, but I should like, with your permission, to mention one or two. At the present moment we have a Committee which is dealing with the vital question of the Electricity Supply Bill. We are consulting with all the other Associations interested in that epoch-making measure, and we hope to be able to send forward very soon indeed the considered opinion of the Council, as representing the whole body of members, after consultation with all parties concerned, on that Bill and we hope that our observations will be helpful to the legislature and that they will receive the attention which we consider is their due. Then again we are endeavouring in good time to help the Electricity Commissioners, whom we hope soon to see appointed. In two respects in particular we are doing this, and both relate to the question of transmission lines. We have set up a representative Committee to consider the whole question of overhead conductors and transmission generally. For a considerable time past one of our Research Sub-Committees has been engaged in investigating the conditions of underground cables transmitting current, and we hope that, as a result of the labours of that Committee and of the Research Sub-Committee dealing with underground cables, we may be able to put before the Board of Electricity Commissioners, when appointed, a great deal of information which will be of the greatest possible importance to them in considering the tremendous problems which will come before them in providing for the supply of electrical energy generated as cheaply as possible for the whole country. Another point to which I ask your permission to refer is the question of patents. We have had a Committee sitting under the chairmanship of Mr. Mordey, one of our honoured Past-Presidents, and that Committee produced a Report which has been recognized as most valuable throughout the engineering world. It was adopted by a Conference comprising all the interests involved in connection with patents, and was put forward as representing the views of all those interested as to the lines on which future legislation should go. That Committee is not, however, resting on its laurels; it has prepared a scheme, which it is believed will be entirely workable, for providing for an Empire patent. If that scheme can be devised on thoroughly practical lines, it will be of inestimable benefit to the inventor throughout the Empire. The field of our activities is ever widening and I am sure it will be a great satisfaction to all our members to know that there is every hope that our building will very shortly be restored to us. That means that next Session we shall be able to resume our activities without the severe handicap under which we have been labouring for the last two years. We shall be able to conduct our business with adequate facilities and we shall be

able again to offer our hospitality to those societies that have been in the habit of meeting under our roof. Now I wish to say a few words about the electrical industry, more especially to those who are not electrical engineers. Electrical engineering is in many respects unique. Primarily it is unique because it is so varied. No other industry is as varied as is that included in the term "electrical engineering." First there is a section which is as much a profession, as purely professional, as the medical or legal profession. Then there is the manufacturing element which corresponds more nearly to the members of the Institution of Mechanical Engineers. Next there are what I may call the *entrepreneurs*, that is to say, those who correspond to the contractor for great civil engineering works, who, while being engaged, as part of their work, in manufacturing, are most largely concerned in the erection of works and the carrying out of the whole of a big undertaking. Lastly, there are the manufacturers of accessories and those who are wholly devoted to commercial work, but who are no less engineers. With a composite body like this it is impossible to compare any other industry that I know of in this country or anywhere else. Not only are there those branches which I have enumerated, but equally in electrical engineering we have a totally different branch comprised in the generic term "telegraphy"—submarine, ordinary land, and wireless telegraphy—all providing work for electrical engineers. Therefore the term "electrical engineer" embraces a great number of totally different professions and occupations. Now the point of these remarks is that I want to bring out clearly that it is impossible to apply to an industry like ours any cut-and-dried scheme. There are other industries which are on similar lines, but they are much more circumscribed than our own. This matter comes up particularly in regard to research. There are many industries which up to the present have not seen much advantage in scientific or even in industrial research. For them it is of inestimable value that there should be prepared a scheme which will enable them to undertake research and which will secure that the money provided by the industry and provided by the Government is properly spent, but I submit that a hard and fast constitution for a Research Association for an industry which has never yet seen the benefit of research is in no way applicable to an industry like ours which is so highly organized and which from its very inception has recognized the necessity and been in the forefront of research. Therefore I would plead with those to whom the question of scientific and industrial research is committed that they will give a sympathetic ear to the representations of the electrical industry and that they will not insist upon carrying out a rigid scheme, splendidly devised though it may be for the bulk of non-scientific industries in this country, but that they will allow the electrical industry to conduct its research and to receive assistance, which that research urgently requires, on lines which are agreeable to the electrical industry and are in accordance with the views which are expressed by its accredited representatives. Another most important point in which our industry differs from others is with regard to the state of rapid flux in which the industry still is. There are many industries which have settled down on lines which are not likely to be disturbed for generations to come, but our own is very far removed from those. In particular in regard to the electrical supply industry is this true. An entire revolution in methods was brought about by the substitution of the turbine for the reciprocating engine. At the present time all large stations must have turbines to drive their generators, and that fact imposes the most serious limitations on the choice of site. To all intents and purposes the site of a very large station is determined almost entirely by the facilities for condensing water which are necessary for a turbine-driven station. But there is no guarantee whatever that finality has been reached. Suppose that a similar invention in regard to internal combustion engines were made as has been made in regard to the turbine—suppose reciprocating internal combustion engines were superseded by purely rotary ones—we should at once have a complete change again. Then there is no reason in nature why some process should not be discovered, by which the potential energy in fuel could be directly converted, without the intervention of machinery, into electrical energy. Then again the whole situation would be radically changed. We should then locate our stations not by condensing water but entirely by the facilities for the supply of cheap fuel. Consequently it is most important that every encouragement should be given to individual enterprise and individual invention. We cannot possibly expect or hope or wish to impose any cast-iron scheme for electrical supply generation on the industry at the present time, and therefore, in conclusion, while fully and heartily appreciating the interest now manifested by Government in our industry, I would earnestly plead that any and every Government control should be as light as possible; that those administering it should be entirely sympathetic to new methods and new discoveries, and that the wishes of the industry itself should be sought in every case. I submit that in no way can that opinion and those wishes be ascertained so well as by consulting our own Institution of Electrical Engineers.

Before passing on to the next toast I have to propose to you some action which is not on the programme, but which will I think be found acceptable. This is the first gathering of what we may call a festive nature which has been held since the outbreak of war, and I wish to propose that we should send to the corresponding Institutions in America, Belgium, France, Italy, and Japan, the following cablegram: "Fraternal greetings to their brother electrical engineers, allies in war and peace, from members of the British Institution of Electrical Engineers assembled at first festival since the war."

The proposal was received with acclamation.

Mr. W. B. Woodhouse then proposed the toast of "Our Guests," to which Rear-Admiral F. L. Field, C.B., and Lieut.-Gen. Sir W. T. Furse, K.C.B., D.S.O., responded.

A reunion was subsequently held.

# PROCEEDINGS OF THE INSTITUTION.

635TH ORDINARY MEETING, 15 MAY, 1919.

(Held at the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 14th May, 1919, were taken as read, and were confirmed and signed.

A vote of condolence was passed with the family of the late Right Hon. Sir J. H. A. Macdonald, G.C.B., LL.D., F.R.S., the members standing in silence.

The Chairman announced the presentation by Captain L. J. Harris of a number of photographs of lignite workings near Cologne, and a vote of thanks was accorded to the donor.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The following donations were announced as having been received and the thanks of the meeting were accorded to the donors :—

*Benevolent Fund :* The Admiralty Electrical Staff, W. Aitken, P. F. Allan, J. F. Avila, E. E. Benham, E. A. Biedermann, W. Brown, E. V. Cheney, W. L. Chubb, F. Coates, Dr. W. Cramp, A. Douglas, T. K. Evans, P. S. Fox, F. H. Francis, A. E. Gott, F. C. Hall, A. N. Haworth, J. C. Kelso, W. E. Lane, A. C. Lock, A. E. McColl, W. McGeoch, Lieut.-Colonel I. W. Massie, J. B. Murray, T. B. Murray, G. Nicholson, R. J. O'Brien-Owen, W. G. Paddock, F. Parry, A. P. Patey, J. Riley, A. Roberts, J. H. Sandiford, S. Simpson, W. G. Simpson, W. H. T. Swire, W. C. P. Tapper, C. Turnbull, and W. A. Vignoles.

*Building Fund :* W. McGeoch and A. Wright.

*Library :* The British Aluminium Co., Ltd., The British Engineers' Association, Lieut.-Colonel A. G. T. Cusins, R.E., The Diesel Engine Users' Association, Major K. Edgcumbe, J. J. Fahie, A. E. Gott, The International Electrotechnical Commission, Messrs. H. K. Lewis & Co., Ltd., P. O. Pedersen, J. Poole, Messrs. Smith, Kempe and Smith, Messrs. E. and F. N. Spon, Ltd., Prof. W. H. Watkinson, The University of Wisconsin, and The Wireless Press, Ltd.

*Museum :* A. R. Bennett, J. J. Fahie, J. W. Wilson, and C. H. Wordingham, C.B.E.

Messrs. D. A. Christian and J. Eck were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

## ELECTIONS.

### *Associate Members.*

Allwood, Samuel John R.
Bannister, Albert, B.Sc. (Eng.).
Blake, Henry Peverall.
Brearley, Sam Ernest.
Claughton, George.
Dean, Henry Jabez.
Fisher, James Charles.

*Associate Members*—continued.

Fowles, Samuel Henry.
Garland, James.
Gooden, Charles Wynn.
Goulden, James.
Hales, George Ernest Butler.
Hall, Clarence Arthur, M.C., B.Sc.
Hayhurst, Herbert.
Henderson, George.
Holland, Gerald Sydney.
Howard, Archibald John.
Jackson, Percy Howard.
Jackson, William.
Jenkins, Daniel, M.Sc. (Tech.).
Kinsey, John Reginald.
Kirk, Malcolm.
Knight, Bertram.
Lightfoot, John James.
Macaulay, James Morison.
McCallion, William James, Capt., M.C.
Marks, Ernest Edward J.
Mason, Walter Frank.
Midgley, Ronald Walter.
Morton, James.
Mould, John.
Parkhurst, Frederick Charles.
Petford, Cecil Henry.
Pinder, Percy Maw.
Rokes, John Milton.
St. John, Richard, Commander, R.N.
Sinclair, Donald.
Slater, John Mackey L.
Slingo, Cecil William.
Smith, Eric Friis.
Somerset, John Alfred.
Stagg, Charles Henry.
Staunton, Rupert Cecil.
Stephens, Henry James.
Stevenson, George Washington, Capt., R.E.
Tanner, William Isaac.
Thomas, Dawson.
Tremayne, Harry Woods.
Vipond, Malcolm Henry Lieut., R.E.
Walton, Edgar Longshaw.
Warrington-Morris, Alfred Drummond, Lt.-Col., O.B.E., R.A.F.
Webster, Shirley Hugh C.
Widlake, Herbert Courtenay.
Wilbraham, Ernest Aaron.
Wood, Harry Herbert E.
Wood, Kenneth Lindsay.

### *Associates.*

Bishop, Walter Frederick.
Graves, Thomas.
Irwin-Packington, Philip.

### *Graduates.*

Bridge, William.
Drew, Bernard.
Fraser, George Alexander.
Goddard, Harry Webster.
Herd, James Fleming.
House, William Edward.
Ingram, Herbert.
Johnson, Eric Maurice, M.Sc. (Tech.).
Kearney-Dodds, John Marjoribanks.
Kerruish, Henry Cannell.
McPhail, Henry James.
Millar, William Robertson.
Moore, Sidney Herbert.
Mukoyama, Hitoshi.
Oliphant, Thompson.
Orton, Joseph William N., B.Sc.
Page, William Arthur A.
Rickard, William Henry (Junior).
Schofield, Bertram Glass.
Sild, August Benet.
Viall, Hugh Roger.

*Students.*

Allam, Eric Bertram.
Barfield, Robert Harry.
Birch, Robert Rule.
Dent, Arthur George H.
Ellis, Francis Arthur.
Fleming, William Kirkland.
Grad, Charles.
Hawkings, Reginald John.
Hinton, Leslie Turner.
Hofman, Stanislas.
Holmstrom, John Edwin.
Horsley, William Douglass.
Jaques, Charles Norman.
Kingsbury, Derrick.
Klein, Moie.
Matthews, Stephen John.
Maughan, James Douglas.
Murray, James.
Parnall, Eric John.
Richardson, Frank.
Rowe, Montague Ernest.
Royds-Jones, Edward Melville.
Schofield, Aaron.
Simpson, Albert Edward.
Wright, Ernest Leslie.
Wright, George Thomas.
Yates, William Patrick.

TRANSFERS.

*Associate Member to Member.*

Howie, Harold Aislabie.
Jobbins, George Gilbert.
Kinnes, Alexander, B.Sc.
Taylor, George Stamp, M.C.

*Associate to Member.*

Hards, Leo Arthur.

*Associate to Associate Member.*

Blake, George Gascoigne.
Lea, William Henry.

*Graduate to Associate Member.*

Alsford, Charles James R., Capt., R.A.F.
Bingham, James Herbert.
Marchinton, William Franklin.
Smiles, Cecil Arthur.
Stephenson, Cyril Heath, B.A.

*Student to Associate Member.*

Bindon, Hugh Doré V.

*Student to Graduate.*

Chapman, Eric Douglas.
Elsden, George Harry.
French, Eric Arthur H.
Miller, Norrell Herbert.
Park, Harold Edward.
Partridge, Charles Frederick.

A paper by Mr. E. A. Laidlaw, Member, and Mr. W. H. Grinsted, Associate Member, entitled "The Telephone Service of Large Cities, with special reference to London," was read and discussed, and the meeting adjourned at 7.55 p.m.

## 636TH ORDINARY MEETING, 22 MAY, 1919.

(Held at the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 15th May, 1919, were taken as read, and were confirmed and signed.

The President announced that the scrutineers (Messrs. F. B. O. Hawes, F. Pooley and R. W. Hughman) appointed at the Ordinary Meeting of the 1st May, 1919, had reported to him that they had examined the ballot papers for the election of new Members of Council, and that the following had been found to be duly elected :—

*President :* Mr. ROGER T. SMITH.

*Vice-Presidents :* Mr. Ll. B. Atkinson and Mr. W. B. Woodhouse.

*Honorary Treasurer :* Mr. J. Devonshire.

*Ordinary Members of Council :* Mr. P. R. Allen, Mr. H. J. Cash, Mr. J. R. Cowie, Dr. W. H. Eccles, Mr. S. E. Fedden, Mr. E. A. Gatehouse, Mr. P. D. Tuckett, and Mr. B. Welbourn.

A vote of thanks was passed to the scrutineers.

Messrs. J. H. Johnson and A. W. Marshall were appointed scrutineers for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

*Members.*

Booth, Augustus Clinton.
Collie, James Hunter.
Dowson, Arthur Henry.
Shaughnessy, Edward Herbert, O.B.E

*Associate Members.*

Abbott, Alexander.
Abraham, Griffith.
Aldridge, Denis William.
Anderson, Henry Mearns.
Ansingh, Herman Kimball.
Ashton, Kenneth Bernard.
Bagshaw, William Browne.
Baker, Arthur Campbell.
Baldwin, Sydney.
Bartholomew, Sydney Charles.
Baxter, Frederick George.
Berry, Davidson.
Binks, Norman.
Botting, Richard George.
Bough, Henry.
Brake, Francis Joseph E.
Brown, John Alexander.
Bruce, John.
Brydon, Sydney, M.Sc.
Caldbeck, Richard Charles.
Canning, Robert Wernam.
Carr, William Brereton H., Capt., R.E.
Castle, Frederick Leonard.
Collins, Robert Henry.
Cook, Nathaniel John.
Cossens, Charles Henry.
Curel, Frederick Grant.
Dalton, John Cornelius J.
Dark, Montague John.
Davies, Frank Broughton.
Dawson, John.
Duncanson, James.
Ebner, Philip Charles.
Evans, James.
Fethney, William Hall.
Firth, Wilfred Walsh.
Foord, Arthur Joseph.
Freeth, Thomas Cecil.
Fuller, James Conrad.
Gibson, Edgar McLean.
Gilberthorpe, Fred.
Gill, Archibald Joseph, B.Sc. (Eng.).
Gillespie, George.
Gough, Raymond Senior.
Green, William.
Grosart, David McDowall.
Gurney, Frank.
Hagen, John.
Hanford, Sydney, B.Sc. (Eng.).
Harcombe, Samuel, B.Sc.
Harris, Ernest Claude.
Higham, Charles Peter.
Hood, Tom.
Inglis, John.
Jamieson, William Eben.
Jolin, Philip Sidney.

*Associate Members*—continued.

Kelly, Arthur Ernest.
Kissel, Frederick Templeton M.
Lack, Charles Tibbit.
Lilly, John Spencer.
Logie, William.
McColgan, Albert John, Lieut., R.E.
McGowan, Frank Morrison.
McKenzie, Daniel Alexander.
McLean, David Alexander.
McNeil, Gordon.
Marr, Joseph Sutherland.
Miller, Stephen Charles.
Mullen, John.
Nelson, James.
Norfolk, Herbert Leslie.
Parker, Frederick Thomas, Major, R.M.E.
Paterson, John.
Pengelly, Frank Ashton.
Phillips, Isaac George E., Captain.
Pinkney, Robert Bruce T., Capt., R.E. (T.).
Powell, William Arthur.
Priestley, Alan, B.Sc. (Tech.).
Pyles, Richard Milton.
Reid, Frederick, B.Sc.
Ridley, William Owen.
Roscoe, Herbert James.
Sarvent, Thomas Arnold.
Saul, Robert Henry.
Scharina, Herman McKay.
Shallis, Boydell, Major, R.E.
Sheers, William Donald.
Smith, George Walter W.
Soi, Mulk Raj.
Spark, Joseph Duncan.
Stenning, Harold James.
Stocks, James Bardner.
Stronach, Henry Maitland.
Swain, Thomas.
Swingler, George Henry.
Taylor, Thomas Arnold.
Thomas, George Taylor.
Thomas, John William, D.Sc. (Tech.).
Thompson, Sydney.
Thomson, John Horn.
Todd, Percy James.
Townend, Harry.
Tylecote, Lewis Hall.
Watt, Robert Alexander W., B.Sc. (Eng.).
Weir, Harry G.
Williams, Alfred Horace.
Williams, John, B.Sc.
Wright, Charles Samuel.

*Associates.*

Dalrymple, James.
Jones, Francis Henry.

*Graduates.*

Baldwin, Douglas.
Bass, Walter Alfred G., B.Sc.
Bruce, George Lance.
Bruce, Robert Francis.
Clements, Henry.
Dingwall, Robert Macfarlane.
Farr, Thomas Arthur L.
Forsyth, John Cossar, M.Sc. (Eng.).
Frith, Gustavus Ridley H.
Gleaves, Leonard Cecil.
Jackson, Clement.
Jones, Samuel Thomas.
Kypriotis, Anastase, B.Sc. (Eng.).
Laing, David Park M.
McPherson, William Lindsay, B.Sc. (Eng.).
Mercier, Gaston.

*Graduates*—continued.

Neill, Henry James.
Philpott, Henry Edwin R.
Proudfoot, Frederick.
Robertson, Alexander Nimmo.
Shiels, John Herbert.
Short, Arthur Henry.
Singh, Narendra.
Stock, Reginald Horace,
Turner, Horace.
Wood, Henry Guy.
Young, Clifford Neil.

*Students.*

Anderson, Ernest Fisher.
Baldwin, Richard Everest.
Batten, Sydney.
Beer, William Ewart.
Bleach, Chris Charles.
Brakenridge, William Donald.
Brooks, Sarah (Miss).
Bulley, Henry Samuel.
Chadwick, Frank Dale.
Coombs, Bernard.
Haywood, Jack.
Huson, Reginald William.
Kennaird, George William.
La Touche, Alexander Arthur D.
Mockford, Frederick Stanley, Lieut., R.A.F.
Monteiro, Julio.
Orr, William John.
Parker, Alfred Henry.
Pick, Thomas Sisson.
Restrepo, Pablo E.
Sercombe, Frederick John.
Stanton, Hubert Bolton.
Stuart, Walter Stanley.
Thornton, Brian Mundell.

TRANSFERS.

*Associate Member to Member.*

Bedford, John Russell.
Carter, Frederick Samuel.
Dover, Alfred Thomas.
Lewis, Thomas Ewart.
Napier, Frederick Disney.
Turner, John Whitfield.

*Graduate to Associate Member.*

Harvey, Ranald John.
Jones, Charles Edward.
Mavor, Albert John, Capt., R.E.
Nierses, James Sydney.
Penard-Fernandez, Enrique.
Welden, William Audley.

*Student to Associate Member.*

Griffiths, Leonard.

*Student to Graduate.*

Duckworth, Herbert.
Gordon, Ernest Alexander.
Mills, Thomas Reginald.
Seaward, William.
Stephens, Cecil Arthur.
Stone, Herbert John, M.C.

A paper by Dr. S. Chapman, F.R.S., was read and discussed, and the meeting adjourned at 7.35 p.m.

## 47TH ANNUAL GENERAL MEETING, 29 MAY, 1919.

(Held at the Royal Society of Arts.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 2.30 p.m.

The minutes of the Ordinary Meeting of the 22nd May, 1919, were taken as read, and were confirmed and signed.

After the President had given a summary of the Annual Report of the Council for the year 1918–19 (see page 322), he moved "That the Annual Report of the Council for the year 1918–19 as circulated be received and adopted."

The resolution was seconded by Mr. W. R. Rawlings.

Mr. E. G. C. Barton suggested the appointment of a Library staff for answering questions sent in writing, particularly from members living at a distance.

Mr. E. H. Rayner asked whether the hour of 8 p.m.

would be reverted to when the Institution is restored to its building. He also urged that every possible opportunity should be taken to announce at the general meetings of members any important decisions taken by the Council, as had been done on several occasions during the present Session.

The President having spoken on the various points raised, the resolution was put to the meeting and unanimously adopted.

Mr. J. E. Kingsbury (Honorary Treasurer) then moved the following resolution : " That the Statement of Accounts and the Balance Sheet for 1918 as presented be received and adopted." In moving the resolution Mr. Kingsbury gave a brief summary of the Accounts (see page 332), and the resolution, after being seconded by Mr. J. Devonshire, was put to the meeting and unanimously adopted.

The following resolution, moved by Mr. J. E. Kingsbury and seconded by Mr. Roger T. Smith, was unanimously adopted : " That the best thanks of the Institution be and are hereby accorded to the Council of the Institution of Civil Engineers for the kind hospitality extended by them to the Institution in placing their meeting room and Library at its disposal, and to the Council of the Society of Arts for their kindness in allowing us the use of this room to-day and on other occasions."

Mr. W. B. Woodhouse then moved : " That the best thanks of the Institution be accorded to the following officers for their valuable services during the past year : (*a*) the Honorary Secretaries of the Territorial Centres and the Local Honorary Secretaries and Treasurers abroad ; (*b*) the Honorary Treasurer, Mr. J. E. Kingsbury, and (*c*) the Honorary Solicitors, Messrs. Bristows, Cooke & Carpmael."

The resolution, having been seconded by Mr. S. Evershed, was unanimously adopted.

The PRESIDENT : I should like to say a few words as to my own personal appreciation of the labours of the Honorary Secretaries of the Territorial Centres : their work this Session has been peculiarly arduous. They are a fund of information upon which the Council is always able to draw when projecting any new work in connection with the Centres, and they have all of them shown the utmost willingness to help in every way. They have displayed conspicuous ability in regard to their duties, and personally I owe them a very great debt of gratitude for the admirable way in which they one and all have organized the visits which it has been my privilege and pleasure to pay to the various Centres.

Mr. J. E. KINGSBURY : Mr. Chairman, I should be glad if you would allow me to thank the meeting for the vote of thanks to the Honorary Treasurer. I want the members to understand that the financial arrangements of the Institution are not really a one-man job. The Honorary Treasurer gets a good deal of the credit at the Annual General Meeting ; but really the Finance Committee, subject to the Council, give consideration to the details of the Accounts, which ensures that it is not possible for any one idea to prevail. A consensus of opinion, which is usually sound, really controls the finance. Throughout my association with the Institution I have been on many Finance Committees, and I have never found one instance in which the members of the Institution forming the Committee have not taken the most serious and practical view of the finances of the Institution. I am quite satisfied that the Institution may look forward to just the same consideration in the future as the Finance Committees have given in the past. I am not going to depreciate the position of the Honorary Treasurer. There is a certain amount of responsibility attached to it. In consequence I feel considerable happiness in my successor, Mr. J. Devonshire.

The President then moved " That Messrs. Allen, Attfield and Co. be elected Auditors for the year 1919–20."

The resolution was carried by acclamation and the meeting adjourned at 3.30 p.m.

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## 637TH ORDINARY MEETING, 30 JUNE, 1919.

(Held at the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 6 p.m.

The Minutes of the Annual General Meeting held on the 29th May, 1919, were taken as read, and were confirmed and signed.

The following donations were announced as having been received and the thanks of the meeting were accorded to the donors.

*Benevolent Fund :* A. Armitage, T. R. Brotheridge, F. S. Carter, E. J. Chawner, A. C. Coward, E. W. Dickinson, The Diesel Engine Users' Association, J. Dubbin, A. R. Everest, P. Freedman, H. J. Goulding, H. N. Holland, M. R. James, W. H. M. Kelman, W. de M. Landon, S. Sharp, Roger T. Smith, J. E. Storr, and J. Wilkinson.

A paper by Captain L. B. Turner, M.A., entitled " The Oscillatory Valve Relay : a Thermionic Trigger Device," was read and discussed, and the meeting adjourned at 7.50 p.m.

# A SUGGESTED BRITISH EMPIRE PATENT LAW.

## REPORT OF COMMITTEE* ON PATENT LAW AMENDMENT.

(*Adopted by the Council, 14 July, 1919.*)

Numerous schemes for enabling patent protection to be secured expeditiously and at a reasonable cost in the whole or in certain parts of the British Empire by means of a single patent have been proposed from time to time, but most of these, though at first sight apparently sound and likely to be beneficial, have the serious practical drawback that to make them effective would involve radical changes in the existing Statute Laws of the different parts of the Empire.

The scheme outlined in this report aims at carrying out what should be the main objects of any Empire Patent Law, viz.

(1) Low cost,
(2) Ease of application throughout the Empire,
(3) Reciprocity,
(4) No change involved in the existing laws of the Empire,
(5) Adherence to the scheme optional by any Dominion.

Under this scheme any person may obtain an Empire patent covering as many of the British Dominions, Colonies, Dependencies and Protectorates, collectively referred to in this Report, for convenience, as Territories, as he may select, by making application to the British Patent Office. The fees payable will be the sum of the existing local Government fees in the selected Territories, plus such small fee as may be charged by the British Patent Office to cover the expense of carrying out its part of the scheme. The application will be examined and the patent granted in the same way as is an application for a British patent, and the specification when printed will bear the names of the selected Territories in which it is effective. Thereafter the patent will be assimilated with the domestic patents in each of the selected Territories and will be subject to the local Laws in such Territories for the determination of validity, infringement and all other questions affecting Letters Patent after grant.

In the Appendix will be found a list of the 48 Dominions, Colonies, Dependencies and Protectorates of the Empire which have their own separate enactments for granting patents.

It is clearly desirable in the interests of inventors and of the public and industry generally that the cost and trouble of securing patent protection throughout the Empire should be materially reduced.

Careful consideration has been given to the suggestion that a patent should be obtainable covering the whole of the British Empire in the same way that a patent in the United States covers all the States in the Union, but there are so many difficulties connected with such a scheme that it is not felt any practical result can be expected of any attempt to elaborate a proposal along such lines. It is believed that the present scheme is practical and has the merit that it can easily and immediately be put into operation without disturbing the existing laws in the various territories in the Empire.

It is assumed that usually an inventor will apply for a patent first in that part of the Empire in which he is domiciled or has his business or manufacturing establishment, in order to secure without delay protection for his invention, and it is not proposed that the existing Patents Acts or Ordinances in the various parts of the Empire should in any way be disturbed. (This, however, does not mean that the Governments of the various Dominions, etc., should not be urged to amend their laws so that they may all be made as uniform as possible in at least their principal provisions.)

The scheme proposes that in each Territory a short Act or Ordinance should be passed to the effect that any Empire patent which has been made applicable to such Territory shall be received and treated by it in all respects as though such patent were a patent which had been granted under the territorial Patent Law. This is important, for otherwise there would exist two classes of patents, and difficulties might arise in interpreting them in the Courts and elsewhere. The fact that the form of the specification and claims of the Empire patent might differ somewhat from that of the domestic patent should not give rise to any practical difficulties.

It is obvious that such an Empire patent as is proposed, in order to secure uniformity, which is essential, must be issued from one centre, and that centre it is suggested should be the British Patent Office.

It is recommended that the Empire patent should be applied for and issued in the same way as a British patent. Where a British patent has been applied for or obtained, the Empire patent will be a duplicate of it.

An applicant residing in any part of the British Empire may apply for a patent either in his own Dominion (being a Dominion granting a patent) or in any other part of the Empire granting a patent and shall have a sufficient period—18 months is suggested—from the date of his first application in any part of the Empire in which to apply for an Empire patent. An Empire patent if applied for within such period shall have a priority date as of the date of application for the corresponding patent first filed in any part of the Empire.

This provision should not give rise to any difficulties, as the practice would follow that of applications for

* See *Journal I.E.E.*, 1919, vol. 57, p. 64.

patents under the International Convention, which gives a period of one year within which applications may be filed in any of the countries belonging to the Convention.

To carry out the scheme it would be desirable to establish an Empire Patent Department of the Patent Office in London, in which all applications for Empire patents would be filed and the appropriate fees paid in respect of the selected parts of the Empire. To this Department would also be paid at the appropriate times such renewal fees as may be necessary for keeping the Empire patent in force in such parts of the Empire as the patentee desired to maintain the patent. The Empire Patent Department would transmit through the appropriate channels the fees received and due to each of the Dominions, etc., in respect of the Empire patents issued and also the renewal fees, if any, paid on such patents to keep them in force.

It is urged that whilst it would be highly desirable for all parts of the Empire to adhere to this scheme for an Empire patent from the outset, it is not necessary that the adoption of the scheme should be delayed until this has been achieved. Valuable progress would result if certain parts only of the Empire decided to adopt it at first and power were given to other parts of the Empire to adhere to the scheme at a later date.

It is strongly recommended that the Empire patent should rest on its own foundation in each part of the Empire. This naturally follows from the suggestion that the Empire patent should be assimilated with the domestic patents in the various parts of the Empire, and read and interpreted in accordance with the law and practice obtaining in each part of the Empire. If, for example, in an infringement or revocation action or like proceeding in the United Kingdom or in any Dominion, the patent were declared invalid, this should not affect its validity in another Dominion in which the validity of the patent was not attacked or in which such an attack failed owing to the circumstances being different. These are substantially the conditions which obtain at present in respect of the separate patents issued by the various Dominions.

As to the fees payable in respect of the Empire patent, it would be very desirable for the various Dominions to agree on a scale of reasonable fees to be payable on application for a patent and at uniform times for the renewal of the same during its term. It is realized that the fees payable at present in respect of both these conditions vary considerably in the different Dominions, in some of them being very reasonable and in others inordinately high, and that the amount of fees payable do not in some cases correspond in amount with the extent of the territory covered or the volume of the trade in a patented article which may reasonably be expected to be done in connection therewith. However, for the same reasons that the establishment of an Empire patent has been advocated along the lines contained in this report, and in order that objections to the early commencement of the scheme may not be raised by the various parts of the Empire on the ground of loss of revenue, it is suggested that the fees payable in any of the Empire Territories should remain as they are at present. It is believed, however, that the reduction in fees which is recommended would be more than made up in the total amount received by the greatly increased number of patents applied for in the various Dominions under the present scheme.

It might be suggested that if the fees in the various Dominions are not reduced no great reduction in the cost of protecting an invention by patent in the Empire under this scheme would result. This, however, is not so, as the cost at present is not so much due to the Government fees payable as to the expenditure necessary in preparing, filing and prosecuting an application for a patent separately in each of the Dominions.

W. M. MORDEY,
Chairman of the Committee.

21*st June*, 1919.

## APPENDIX.

*Empire Dominions, etc., having their own separate enactments for granting patents.*

| | |
|---|---|
| Australian Commonwealth. | Johapur. |
| Bahama Islands. | Johore. |
| Barbados. | Kedah. |
| Bermuda. | Kelantan. |
| British Guiana. | Leeward Islands. |
| British Honduras. | Malta. |
| British Solomon Islands Protectorate. | Mauritius. |
| | Mysore. |
| Canada. | Newfoundland. |
| Ceylon. | New Zealand. |
| East African Protectorate. | North Borneo. |
| Egypt. | Nigeria. |
| Falkland Islands. | Nyassaland Protectorate. |
| Federated Malay States. | Rhodesia (Southern). |
| Fiji. | St. Helena. |
| Gambia. | St. Lucia. |
| Gibraltar. | St. Vincent. |
| Gilbert and Ellis Islands Colony. | Seychelles Islands. |
| | Sierra Leone. |
| Gold Coast Colony. | South Africa (Union of). |
| Grenada. | Straits Settlement. |
| Hong-Kong. | Travancore. |
| Hyderabad. | Trinidad and Tobago. |
| India. | Uganda Protectorate. |
| Jamaica. | Zanzibar. |

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# ELECTRIC POWER SUPPLY DURING THE GREAT WAR.

By Arnold B. Gridley and Arnold H. Human.

PART II.*

(*Received* 13 *August*, 1919.)

## Electrical Plant Manufacture.

**1.** *Unprecedented demand.*—Those who have read Part I of the record of the War activities of electric supply undertakings must have appreciated that the electrical manufacturers of Great Britain were never before called upon for a greater output of electrical machinery of all kinds than during the War period. It cannot be claimed that in pre-War years British electrical manufacturing firms, with but one or two happy exceptions, reaped an adequate reward for their efforts. They were faced with severe competition from America and Germany, particularly the latter, whose dumping policy, financially assisted by the banks, often made it impossible for British firms to compete profitably. British cable manufacturers, through superior organization and the help of their Association, successfully and profitably met foreign competition, and were generally in a stronger position than makers of electrical plant, machinery, and equipment.

**2.** *Secured home market.*—The War secured the Home market to British capital and labour. Further to consolidate and strengthen their position, many firms have now amalgamated, with the result that the heavier engineering can be said to be in the hands of but four or five strong groups, better equipped in every way to manufacture the largest sizes of turbo-alternators, etc., which will henceforth be called for, and to compete for export trade.

**3.** *British manufacturers' chance.*—It has already been shown that the kilowatt capacity of generating plant installed or ordered by public service undertakings during the War aggregated 1,143,000 kw., a total equivalent to the plant installed in June 1914. Practically the whole of it was of British manufacture. This large output, to which must be added the plant ordered by Government Departments, private firms, the Allies and—to such extent as was permissible—by the Colonies and friendly neutrals, indicates in some degree the task fulfilled by the manufacturing industry. It follows that an unprecedented demand for motors, transformers, switchgear, cable, etc., had to be met. Equally busy were the makers of boilers, steam piping, condensers, pumps and other auxiliaries.

**4.** *Products mainly, but not wholly, standard.*—While it can be stated that generally the electrical manufacturing industry was fortunate in being called upon to supply their more or less standard products, it will surprise many that some firms, while maintaining or augmenting their output, were nevertheless able to assist substantially in the direct production of War munitions. To what extent will be shown later.

**5.** *Every manufacturer busy.*—It was not to be expected that comparative data as to output of electrical machinery would be obtainable from competing manufacturers. It is, however, evident that with orders to fulfil—totalling well over 1,000,000 kw. of generating plant—no manufacturer could have been idle during the War period. The output attained necessitated considerable workshop extensions and the addition of costly machine-tool equipments.

**6.** *Production hampered by calls for men for Active Service.*—Patriotically, though perhaps unwisely, the enlistment of employees, skilled as well as unskilled, was at first encouraged. This necessitated from time to time the up-grading of less experienced men, and the division of some of the more or less complex manufacturing processes into a number of simpler ones which could be entrusted to inexperienced male and female labour. Although greater cost and less efficiency resulted, this procedure was, under the circumstances, satisfactory.

**7.** *Women employed and results.*—From a number of opinions expressed, the employment of women labour has been found satisfactory on simple repetition process work in mass production, but in other work it has been

* For Part I see page 406.

scarcely encouraging. Boys have shown more initiative and enterprise, and were better time-keepers. Wages rates for women and girls were so much more than those normally paid to boys that trouble was caused, and piecework rates had to be doubled. Some firms were greatly handicapped by housing difficulties, and by the competition of higher wages rates paid to local munition workers, while the constant training of new hands limited production.

**8.** *Difficulties through restriction of imported raw materials.*—Difficulties in obtaining raw materials from the Continent, and the limitation of shipping facilities, made it essential that new sources of supply should be found or their production or manufacture developed at home. The latter often necessitated a great deal of research work, and the design and installation of special and costly machinery. As examples it is only necessary to mention lamps, magnetos, and carbons, out of hundreds of such cases. The energy and resource shown by manufacturers and their depleted staffs cannot be too highly commended.

**9.** *Variety of war work.*—It will be noted from the brief descriptions which follow of the munition work undertaken by the electrical manufacturers that their output was of a varied type, from primers and wireless valves to completed heavy guns, aeroplanes, seaplanes, flying boats, etc.

**10.** *Handicap through importation of turbine discs.*—It was unfortunate that turbine builders remained so dependent throughout the War upon the importation of turbine discs from abroad. There would appear to be no insuperable difficulty in getting British forgemasters to produce all the turbine wheels required if the turbine makers will but get together and agree upon a reasonable specification with firms engaged on the production of steel forgings and castings. Unhappily a great deal of plant was delayed during the War by the late delivery of turbine discs which were ordered from America, or by effective submarine attacks upon ships carrying consignments. Efforts were made during the War to remedy this situation by home production, but were limited by the overwhelming demand upon steel foundries for even more urgently needed requirements. While it is true that British quotations compared unfavourably with prices tendered by America and Continental firms, the placing of bulk orders should enable British firms to compete in future.

**11.** *Development of cooking and heating appliances.*—Great activity in the production and use of electrical cooking and heating apparatus was evidenced during the War. Much of the heating apparatus supplied to Government Departments was of a special nature, and, owing to the confidential purpose of many of the processes adopted, it is impossible to give details which would be of the greatest interest. The following data do, however, give some indication of the abnormal amount of work carried out for the particular purpose:—

| Apparatus | Pieces of Apparatus | Kilowatts | Persons catered for per day |
|---|---|---|---|
| Electrical cooking apparatus supplied to canteens, munitions works, hospitals, and national kitchens | 4,800 | 71,055 | 316,500 |
| Electrical cooking apparatus supplied for use afloat | 12,750 | 27,750 | 63,000 |
| Heaters for gun mountings to prevent guns from jambing or freezing when in use in aeroplanes | 55,500 | 1,020 | |
| Heaters for aeroplane engines to prevent freezing when standing awaiting orders | 24,000 | 12,000 | |
| Auxiliary plant or apparatus used in connection with the heating of oil for furnaces, primers for aeroplanes engine, smoke screens, decoys, metal baths, muffles and crucibles, branders, glue pots, soldering irons, special heaters for explosive works, band heaters for shrinking bands on to shells, wood seasoning ovens for seaplane work, armature dryers, airmen's suits, resin boilers, radiators and heaters, immersion heaters, copper circulator heaters for seaplane engines, etc. | 39,600 | 52,500 approx. | |

This makes a total of 160,650 pieces of apparatus with a total kilowatt capacity of 164,050.

**12.** *Manufacture almost wholly British.*—It is interesting to note that the material used was almost wholly of British manufacture with the exception of regulation switches and, to a small extent, the wire used for heating, such as Nichrome. In the earlier part of the War the importation of "Hart" switches and Nichrome and Nichrome 2 from America was permitted, but later on British manufacturers were able to supply a good deal of the heating wire, and therefore the import of Nichrome was then prohibited. It is also of interest to state that the type of element employed afloat differed from that employed on land. In the former case mica was almost universally used, and in the latter case fireclay. There was some slight difference in the method of construction, but the main feature in each case was similar.

**13.** *Control policy of Ministry of Munitions.*—The control of manufacturers' output was not instituted by the Electric Power Supply Department until May 1916. It was a deliberate policy to exercise control as lightly as circumstances made possible. The main

purposes were to ensure that no work was put in hand without the authority of a priority certificate, that orders were executed in conformity with Priority gradings, and that buyers of plant, etc., were correctly quoting the certificates issued to them. This procedure had become essential. Many buyers used priority certificates wrongly, mostly due to misunderstanding and not intent.

**14.** *Regulation of output.*—All the important electrical manufacturing firms had their output thus regulated. Their returns of orders received were submitted with exemplary regularity, and they were generally informed by return of post that manufacture could proceed, only the cases which needed investigation being held up. The large number of returns to be examined, and the correspondence involved during a period of such abnormal activity in the electrical industry, can readily be imagined.

**15.** *Surveillance of manufacture found unnecessary.*—Apart from this check on orders dealt with, manufacturers were otherwise interfered with but little. They were not kept under continual surveillance by a host of inspectors, as would appear to have been necessary in some other industries. No inspection of manufacture was made. It would not have been difficult for manufacturers to execute orders unauthorized by certificates, or to ignore priority grading. Firms were, however, trusted, and this confidence was not misplaced. Evidence was forthcoming as to this, because the deliveries of plant to their clients, who were also controlled by the same Department, were known. A letter from the Ministry asking for special attention to be given to urgently needed plant had as much effect as any amount of inspection. In no case was any proof shown of Government regulations being ignored. It is pleasing to be able to place this on record.

**16.** *No interference between buyer and seller.*—Buyers and sellers were also left a free hand as to with whom they might do business. No buyer was instructed that he must go to any particular manufacturer. It will generally be held that this was a sound policy, although some firms suggested that orders should have been parcelled out by the Ministry—a somewhat invidious responsibility.

**17.** *Small separate plants discouraged.*—Not infrequently the necessity of first obtaining priority certificates enabled the suggestion to be made to power users, proposing to install separate generating plant, that they should buy current from their local power supply undertaking instead. Several small plants were thus avoided.

**18.** *Rate of production.*—During the latter half of the War period the annual rate of production of electrical plant was approximately as follows:—

| | |
|---|---|
| Generating plant .. .. | 400,000 kw. per annum |
| Motors .. .. .. .. | 600,000 ,, |
| Transformers .. .. .. | 500,000 ,, |
| Converting plant .. .. | 110,000 ,, |

**19.** *"War stock" authorized when necessary.*—Now and again the order of work passing through the shops of some firms left gaps which it was desirable to fill. Authority was given in such cases for a limited number of turbo-alternators of useful size to be put in hand and treated as "War stock" machines. These were subsequently found most useful in meeting urgent and unforeseen demands, and those on hand found a ready sale after the Armistice.

**20.** *Restriction of electrical imports and exports.*—The importation of electrical machinery into Great Britain was almost totally prohibited during the War, even from Neutral countries. Reliance was placed upon the ability of British manufacturers to meet all demands. A large export business could have been done with the Colonies and Neutrals, but it was found impossible to grant priority certificates or to allow British firms to take such orders. Unfortunately considerable business thus went to the United States and Japan, an inevitable consequence of the War. Markets thus temporarily lost should soon be recovered, provided the policy of capital, labour, and of the Government is wisely framed.

**21.** *Close co-operation with the B.E.A.M.A.*—In 1917 a Committee of members of the B.E.A.M.A. was set up under the Chairmanship of the Technical Adviser of the Electric Power Supply Department. The purpose of this Committee, which held fortnightly meetings, was to place views or recommendations of the B.E.A.M.A. before the Ministry whilst the manufacture and disposal of electrical plant was controlled.

**22.** *Restriction of fully enclosed motors, etc.*—An important matter approved by the Committee was the control over the manufacture of fully enclosed dynamos and motors. Users of motors were—and unfortunately still are to some extent—in the habit of specifying fully enclosed machines where a pipe-ventilated pattern would be more satisfactory and require less material and labour, a matter of first importance at the time. Instructions were issued to all electrical manufacturers prohibiting the manufacture of fully enclosed machines without approval. Certain exceptions—such as for motors working in the open on board ship and in steel works, etc.—were allowed. Every customer who specified a fully enclosed machine had to submit particulars proving its necessity before the maker could proceed. No trouble or friction was caused. At the most two days only were required to secure the required permission or to satisfy the customer that a pipe-ventilated machine would not only better serve his purpose, but be cheaper and more efficient.

**23.** *Steps to standardize manufacture.*—With the same object in view, namely the reduction of materials and of skilled labour in particular, the Committee agreed that no manufacturer should, without approval, depart from his standard design to suit a customer's particular, and in some cases peculiar, design. This proved a very useful measure, as certain users were, for no obvious reason, in the habit of specifying non-standard sizes of shafts and other dimensions, which would, if allowed, have interfered with standardization in manufacture when economy of labour and material was of first importance.

**24.** *Other assistance invoked.*—Other matters upon which the Committee assisted the Ministry included questions of imports and exports, release of pivotal

men from the Services, provision of raw material, etc.

**25.** *Workshop extensions approved.*—The increase in the volume of work handled has necessitated a large number of workshop extensions during the War. Unfortunately, as time went on, all building extensions became more and more rigidly scrutinized owing to the increased shortage of building material, labour, etc. All but one or two factory extensions were ratified, and in this respect the electrical industry was but little hampered. It is true to say that the great part being played by electricity in munitions production was quickly recognized by Government Departments and Committees.

**26.** *The German electrical industry as affected by the War.*—The importance to Germany of her electrical industries during the War was enormous; the widely spread activities of the A.E.G. and the Siemens-Schuckert groups embracing facilities which could rapidly be devoted to the direct production of munitions of war. The interests of these two firms alone are valued at upwards of £250,000,000. From time to time during the War particulars filtered through which gave some reliable indication of the difficulties the German electrical industry had to cope with. The Naval Blockade cut off the overseas supplies of many of the important essentials for manufacture, which threatened to cripple production. The available supplies of copper, brass, nickel, rubber, mica and other materials, customarily imported, were commandeered by the German Government for direct war purposes, and no further supplies from abroad were obtainable, except in rare cases of ships evading the blockade. Substitutes had in consequence to be sought for if production were to be maintained or augmented. In any case, it was difficult enough to meet Army requirements, and next to impossible to spare anything for commercial needs.

**27.** The two firms above mentioned were the first to substitute aluminium for copper wire in machine windings, but it was soon found that the high cost and the growing scarcity of this metal necessitated recourse to the use of zinc wire. At first this wire was not successful owing to its brittle nature, but, ultimately, a more elastic and serviceable form was produced and firms commenced to manufacture zinc motors, which served their purpose more or less satisfactorily. The machines thus constructed were very nearly twice the size of the old type, and iron collectors were used. Transformers with zinc windings were also made, and the A.E.G. built transformers of this type of 7,500-k.v.a. capacity, which proved satisfactory. At a later date, reversion was made partly to aluminium windings, and only in exceptional cases was the use of copper permitted in the construction of electrical machines. Conductors were made of iron, aluminium, and zinc wires, little copper being permitted for this purpose

**28.** Substitutes for rubber were adopted for the insulation of wires, the most satisfactory being impregnated paper. Resistances, contact controls, etc., were made of iron. Switches, lamp bases, etc., were made of "Sherardized" sheet iron. Iron was mostly employed in high-tension apparatus, current-carrying parts—except contacts—being made of zinc. Meters made of iron and zinc were produced The whole trend of research was directed to render Germany independent of the import of raw material, and to free for War purposes the maximum amount of the essential raw materials referred to.

**29.** As an example of the search for copper which indicated the scarcity of this metal, the following paragraph is of interest:—

"The Auldberg Railway were requested to set free the largest possible quantity of copper for Government purposes. By building a substation at the centre of the railway system, and by raising the transmission voltage from 3,000 to 10,000 volts, iron wires being substituted, about 11 tons of copper, and 8 tons of lead were released."

**30.** Despite the restrictions and great difficulties which hampered them, the German manufacturing firms were far from non-progressive, and, while there are some in this country who still have misgivings about using units of 25,000-kw. capacity, the A.E.G. manufactured during the War a 7,000-volt turbo-alternator of 60,000-k.v.a. capacity, the turbine blading of which was made of steel, without nickel, worked out of the solid. A second and similar machine has recently been constructed.

**31.** Particulars of the output of electrical manufacturing firms are as follows:—

*Daniel Adamson & Co., Ltd.*—This firm was mainly engaged in the production of turbo-blowers, but a considerable amount of their energies was also devoted to the production of shells and submarine mines.

*Belliss & Morcom, Ltd.*—In addition to the manufacture of power plants, some of the requirements of the various Services for submarine, tug and trawler engines, 18-pounder gun parts, 6-inch howitzer gun parts, and airship and aircraft engine parts, were also met. The chief difficulty encountered was owing to the variety of the work, and its non-repetition character, but by special efforts, including the assistance of women labour, they were able to meet the demands of the various Services.

*British Thomson-Houston Co., Ltd.*—The output of electrical machinery and plant was slightly increased, over 600,000 kw. of turbo-generators being manufactured. In addition, turbines for Navy boats, wireless generators, and a very large quantity of other war material including shells, bombs, gun parts, mines, tank parts, wireless valves, barbette hoods were produced. Over 40,000 magnetos were manufactured for aircraft purposes, after much research and experimental work, a new development of the first importance. The lamp production records give the following figures for distribution: —Direct Government 45 per cent; Class A and B 50 per cent, showing that very few lamps were available for export or domestic service. The whole output of tungsten and molybdenum has been obtained at the works, the rate of production of tungsten being now five times, and of molybdenum 12 times the 1914 output.

*British Westinghouse Electric and Manufacturing Co., Ltd.*—Although changes had to be made in the nature of manufactures to meet War conditions, the pre-War products of the firm were considerably augmented, the demand for large power turbo-plants and motors with the accompanying equipment being very great. Certain parts of the factory were turned over to actual war-material manufacture, and in 1917 over 5,000 tons of shells and fuses were turned out. In addition, gun parts, submarine engines, electric-contact and other mines, Ricardo engines, tank parts and paravanes have been manufactured in large quantities. The labour turn-over during the war has been 30,000 and the total number of employees who joined His Majesty's Forces was 3,500.

*Brush Electrical Engineering Co., Ltd.*—The pre-War manufacture of turbo-plant, transformers, motors, etc., were augmented by requisitions for munitions factories, dockyards, and controlled power stations. On completion of large rolling-stock contracts, new shops were erected and important aircraft contracts undertaken. In October 1915 the first machine was delivered; and a large number of "Short," "Maurice Farman" and "Avro" types of seaplanes and aeroplanes were turned out, with uniform success, the company establishing its own flying-ground and delivering by air after complete flying tests. In addition, some thousands of paravanes ("Otters") and a large quantity of shells and bombs were manufactured. On Armistice Day 27·5 per cent of the employees were women, as against 3·7 per cent pre-War.

*Dick, Kerr & Co., Ltd.*—This firm, as an exception to the general practice of electrical manufacturers, temporarily abandoned their pre-War products and devoted themselves entirely to direct War work. With the exception of some 100 petrol-electric tractors, the whole works output has been confined to Army and Navy requirements; shells from 12-pounder to 13·5 naval, 6-inch howitzers, flying boats, railways and transport requisites being the main items. Of shells alone over 100,000 tons finished weight were forged and completed. In addition, many Government establishments were equipped. For example, the Hackney Marshes National Projectile Factory for the manufacture of 15,000 6-inch H.E. shells per week was built, equipped, and later taken over by the Ministry. Over 3,000 women were employed in November 1918—a tenfold increase over the pre-War figure.

*Fraser & Chalmers, Ltd.*—At this firm's works, in addition to the pre-War products, Diesel and other engines for Admiralty work and turbos for standard ships have been manufactured as well as gun parts, etc. Much work has been done in mining plant for lead, copper, zinc and wolfram and the like; also with dry gas cleaning plant, because of the increase in iron and steel output, and the recovery of the valuable by-product "potash."

*General Electric Co., Ltd.*—At the signing of the Armistice, 90 per cent of the turn-over was taken up by direct and indirect Government demands, the bulk of the remaining 10 per cent being on work of national importance. The pre-War manufacture of heavy machinery was much augmented, whilst special small dynamos and motors for the Mechanical Transport Department were made in large quantities. The carbon works were doubled, and the whole output placed at the Government's disposal, whilst field and trench telephones in enormous quantities were supplied from the telephone works. In addition, new works were laid down to meet Government demands for magnetos for aeroplanes; and great quantities of shells, gun parts, aeroplane parts, submarine detector gear, etc., have been supplied. A new building was also erected for the making of valves for wireless work, and over 120,000 of these valves were produced in the past year.

*C. A. Parsons & Co., Ltd.*—The main pre-War products—turbines for driving electric and other machinery, and searchlight projectors—were considerably augmented; and in addition, at the request of the Admiralty, marine turbines were constructed in large numbers. During the last three years some 175,000 h.p. of marine turbines have been turned out for battleships, cruisers, destroyers, patrol-boats and standard ships, whilst over 750,000 h.p. of turbine and electrical machinery have been produced. The output of searchlight projectors, ranging from 10-inch to 78-inch diameter, has been increased tenfold, this Department of the firm being the largest manufacturers of such reflectors in the world. Experiments for the Admiralty have been carried out on submarine and mine warfare. Large numbers of standard gauges for shell and other work have been made for the Ministry.

*Richardsons, Westgarth & Co., Ltd.*—This firm's principal pre-War productions for power-station equipment were steam-turbines, condensing plant, boilers, and heat accumulators. The construction of marine steam-turbines was commenced shortly before the outbreak of War, following which the works were placed at the disposal of the Admiralty. The War output of marine turbines for destroyers and patrol-boats was over 122,000 h.p., mostly of the Parsons type, but later in the War the Brown-Curtis type was largely adopted. The latter type included a number of standard turbines with double-reduction gear for standard cargo vessels. In addition, 27 land turbines were constructed, aggregating 85,000 kw. The largest of these were one 20,000-kw. and one 15,000-kw. for Manchester Corporation, one 12,000-kw. for the Newcastle Electric Supply Company, and one 10,000-kw. turbine for the London Electric Supply Corporation. These units were the largest actually at work of the single-cylinder type, running at 1,500 r.p.m. The builders were indebted to the National Physical Laboratory, Metallurgical Department, for assistance rendered in obtaining suitable steel for the higher stressed blades in these large machines. The boiler department turned out over 75,000 h.p. of Yarrow-type boilers. The employment of a large number of women in the turbine and boiler departments was found satisfactory under proper supervision. At the Middlesbrough Works a very large output of shells was turned out, practically entirely by women, of whom 360 were employed. The firm's standard reciprocating marine engine was supplied in large numbers for mine-sweepers, sloops, patrol-boats and ice-breakers amongst other vessels.

*Siemens Brothers & Co., Ltd., and Siemens Brothers*

*Dynamo Works, Ltd.*—At the Woolwich Works civilian work was practically abandoned, and to meet Government demands new shops were erected and equipped, and double shifts instituted so that the normal output was more than doubled. About one-third of the male employees joined the Forces and female labour was substituted, 2,600 women being employed in a total staff of 5,600 at the close of the War. Of the usual products other than cables, only incandescent lamps and dry batteries were continued, over $2\frac{1}{4}$ million dry cells being supplied during the last six months of the War. Field-cable manufacture was much increased, 2,000 miles per week being supplied for the Allied Forces in addition to 80 miles per week of heavily armoured trench cable. Aircraft magnetos, Fullerphones, anti-aircraft searchlights, hand grenades and other war munitions were also manufactured, and experimental work was undertaken in connection with sound detectors and cables for submarine catching. At Stafford, in addition to standard products, much direct munition supplies were manufactured, including trench mortars, parts for 6-inch and 8-inch howitzers, shrapnel shells, adapters, fuses, parts for aeroplane engines and aerial torpedoes. Generating plant was supplied for a number of camp lighting installations, shell factories and power stations. Included in the latter were a 17,000-k.v.a. and a 15,000-k.v.a. turbo-alternator. Motors of the largest sizes so far built in this country were manufactured for rolling mills.

*Vickers, Ltd.*—At the Sheffield works the output of the heavier electrical plant has been more than three times the pre-War figure, and the increase was secured mainly by continuous working and the installation of additional tools. The whole of the work was on direct contracts with the Admiralty, War Office, Ministry of Munitions, or for controlled establishments, and was of the same general type as pre-War. At the Birmingham works the output, mainly of smaller electrical plant and control gear, was increased by about one-third, and in addition a considerable amount of direct war material was manufactured. Export orders had to be consistently refused, and machinery required by previous customers had to be obtained from foreign competitors able to supply it.

*Willans & Robinson, Ltd.*—The decision of the Directors to concentrate largely on War work substantially altered the character of many of the firm's productions. The manufacture of the Canton-Unne aeroplane engine was commenced within one week of the declaration of War, and some 200 engines of 200 h.p. and 150 h.p. sizes were completed within 12 months. The 6-cylinder Sunbeam engine was then proceeded with, and about 100 of this type completed, in addition to detail work in connection with Rolls-Royce, Le Rhone, and other makes. Other manufactures included steam engines for kite-balloon winches, tank parts, gear-cases, paraffin engine parts and a large number of 8- and 12-cylinder submarine Diesel engines. Turbines were also manufactured for H.M. ships, including destroyers and patrol-boats. Some 40 turbines of aggregate output of 100,000 kw. and 60 Diesel engines of 15,000 h.p. were completed for power stations, munition factories, dockyards, and air stations, and a large quantity of turbine-driven ash expellers and bilge pumps supplied to the Navy. A large output of bronze castings, chiefly for warship propellers and submarine conning towers, was maintained, and after numerous experiments, aluminium castings were produced to meet the large requirements of the Air Board for aluminium cylinders. 60-pounder shells were machined and filled in large quantities, and in the earlier part of the War, powder cases were also constructed.

**32.** The foregoing information does but limited justice to the work carried out by the electrical manufacturers, but lack of space prohibits a more detailed account or reference to the important work of smaller firms. Sufficient has been said, however, to indicate how great a debt the country owes to electrical engineers, whether engaged in the manufacture of plant or producing and supplying current.

**33.** It has been felt, and with justice, that some record should be preserved of the great activities displayed and the responsibilities borne by electrical engineers during four of the most important years in the world's history, and it has been a privilege to the authors to be invited to compile this record. They are grateful to all those who have supplied the data which has greatly enhanced the interest of the record, and they regret if they have failed to do justice to any undertaking or firm whose share in the War burden has been inadequately referred to. Electrical engineers can rest assured that the war effort put forth has established on broader and securer foundations an industry which is of vital consequence to the future prosperity and health of the nation, and which has in front of it an expansion infinitely greater than that which it has experienced in the past.

## APPENDIX.

### Erratum in and Omission from Part I.

*Page* 410, *par.* 30, *line* 6: For "8,000 kw." read "10,500 kw."

*Page* 407, *par.* 13: After "Leeds Corporation" add "Woolwich Borough Council 31,425,000" units. (This undertaking is therefore eighth in point of view of war expansion of output.)

# LARGE POWER TRANSFORMERS.

By A. G. Ellis, Associate Member, and J. L. Thompson, M.Sc., Associate Member.

(*Paper first received* 15 *January, and in final form* 20 *February*, 1919; *read before the* North-Western Centre, 11 *March, and before the* North-Eastern Centre, 17 *March*, 1919.)

Synopsis.

(1) Development.—Progress in size of modern power stations, generating units and voltages.
(2) Limiting sizes of transformers as determined by transport, handling and cooling.
(3) Price and weight per k.v.a. in relation to method of rated output, frequency, voltage, and cooling.
(4) Choice of type:—
  (*a*) Methods of cooling.
  (*b*) Single *v.* three-phase units.
(5) Proportion of losses and overload capacity.
(6) Comparison of core and shell types.
(7) Protection against short-circuit.
  (*a*) Inherent reactances.
  (*b*) External reactances.
(8) Safety factors.
  (*a*) Electrical.
  (*b*) Mechanical.
  (*c*) Thermal.
(9) Transformers for interlinking of stations.
(10) Transformers for rotary converters.
(11) Operation and care of transformer installations.
  (*a*) Switching in and out.
  (*b*) Drying out.
  (*c*) Periodic inspection.
(12) Influence of war conditions on transformer manufacture.
  Cost of material—iron, copper, insulating materials and oil.
  Labour and export restrictions.

## (1) Development.

Modern developments and indications of future progress in electrical power generation and distribution tend towards centralization of power, involving naturally an increase in the sizes of power stations and of generating and transforming units. This has been engendered by the necessity for more economical generation and distribution of power, in relation to such questions as conservation of coal and labour.

Within the last decade the average and practicable sizes of power stations and of generating and transforming units have increased practically tenfold, so that to-day the order of size of unit for large stations is from 15,000 to 50,000 kw.

The natural increase in pressures associated therewith has led us to generating voltages up to 11,000 volts and to transmission voltages up to 150,000 volts in America and on the Continent. In this country the transmission voltage has hitherto not exceeded 30,000 volts, but there are projected schemes for 60,000-volt transmission now under consideration.

For electrical machinery to cope with the requirements of such installations it has unfortunately been usually considered desirable to go to America or the Continent. While British manufacturers have had ample opportunities of taking a front place so far as large turbines and generators are concerned, equal opportunities have not been afforded in transformer and switchgear work. This has been due largely to the limited home demand for such apparatus, although the export market has afforded a wider scope.

From the foregoing it is evident that the home demand for large and high-voltage transformers in particular will, in the near future, be much extended, and British manufacturers have experience available which will cope with this demand.

The object of the present paper is, firstly, to examine the possibilities and limitations of large and high-voltage transformers, with reference to conditions of manufacture, transport, handling, installation and operation; and, secondly, to inquire generally into the leading questions regarding transformers which present themselves to engineers engaged in the design of large installations.

## (2) Limiting Sizes of Transformers.

For home service it is in most cases desirable to transport transformers complete in their tanks, thus minimizing erection work and cost. Where possible it is also desirable to ship the transformer complete in oil, generally obviating drying out on site.

The size of transformer which can be transported and handled complete is limited, first, by the loading gauge restriction and maximum truck size and loading, and secondly by the handling facilities and crane capacity on the customer's premises.

Crocodile trucks up to 50 tons loading weight are available in this country, with maximum loading dimensions of 30 feet in length, 8 feet 5 inches in breadth, and 11 feet 8 inches in height (see Figs. 1*a* and 1*b*).

Based on these data the maximum rating of single and three-phase transformers of the self-cooled and artificially cooled types which can be shipped complete (with terminals removed) can be determined.

### Transformers Shipped Complete in Oil.

(*a*) *Oil-immersed self-cooled transformers.*—The maximum rating is limited by the radiating surface of a tank of overall dimensions within the above limits. Such a tank could be constructed to radiate a total loss of about 50 kw. with a temperature rise of 50 degrees C.

This would be practically the total loss of a three-phase 50-cycle transformer of about 5,000 k.v.a. whose

efficiency would be practically 99 per cent at full load. An outline of such a tank is shown in Fig. 2.

The tank shown is of plain boiler-iron construction fitted with external cooling tubes. The same radiating capacity can be obtained within the prescribed dimensions by other types of construction, as, for example, a corrugated sheet-iron tank fitted with permanently-attached corrugated oil pockets.

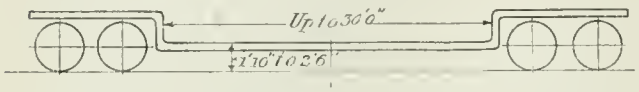



FIG. 1*a*.—Outline showing dimensions of crocodile truck.

For a single-phase transformer the maximum rating is further determined by the shape of the transformer carcase, which limits the rating for shipment complete to about 3,000 k.v.a. at 50 cycles.

The above limits are approximate and for voltages up to 50,000 volts, but they are not greatly influenced by the voltage or type of construction for these fairly large outputs.

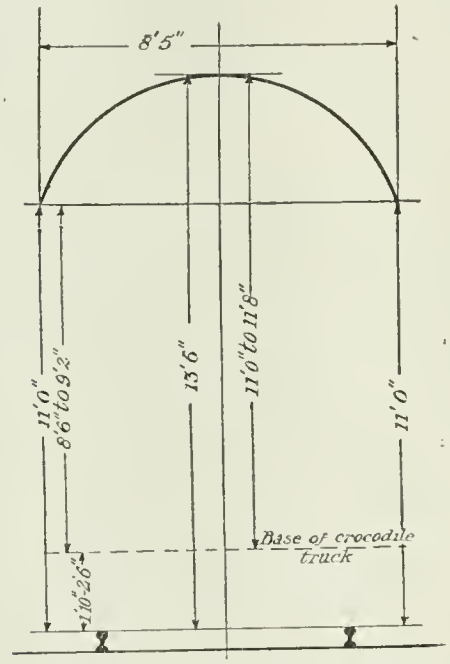



FIG. 1*b*.—Outline showing railway loading dimensions.

For 25-cycle transformers the limiting ratings are about 70 per cent of the 50-cycle limits, i.e. in round figures

3,500 k.v.a. three-phase, and
2,000 k.v.a. single-phase.

(*b*) *Oil-immersed water-cooled transformers.*—The maximum rating of water-cooled transformers with internal cooling coils is limited by the space required for these coils in the tank. This consideration limits the practicable sizes to about

15,000 k.v.a. three-phase, and
10,000 k.v.a. single-phase,

at 50 cycles, although such large units of this type are not to be recommended in preference to the forced-cooled type with oil circulation and external coolers.

Such transformers come well within the limits given in the next section for forced cooling, these limits being recommended on account of the considerable headroom required for the cooling pipes at the top of the transformer.

(*c*) *Oil-immersed forced-cooled transformers.*—The limiting ratings of water-cooled transformers with forced oil circulation which can be shipped complete in their tanks may be determined as above from the railway

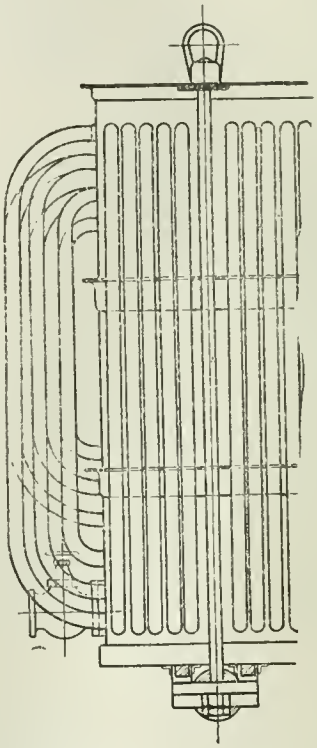


FIG. 2.—Outline of tank with external cooling tubes for 5,000-k.v.a. three-phase 50-period oil-immersed self-cooled transformer.

Approximate overall dimensions:
Length 9 ft., breadth 5 ft., height 12 ft.

maximum loading gauge (see Figs. 1*a* and 1*b*). In the case of water-cooled transformers the rating is not limited by the cooling surface of the tank, but only by the internal dimensions of the tank and the necessary clearance between the windings or carcase and the tank sides.

A three-phase transformer filling out such a tank would have a rated output of approximately 40,000 k.v.a. for voltages up to 50,000 volts. Its weight, excluding tank and oil, would be about 37 tons, and the tank would weigh about 8 tons and contain about 13 tons of oil, making the total weight 58 tons.

Whether such a transformer could be shipped complete in oil depends only on the loading weight of the available crocodile truck, the crane capacity available, and the handling facilities in the factory and on site.

In a factory handling such large transformers a crane would be installed for at least 50 tons; also in a power station where units of such large capacity would be installed a similar crane would also be provided.*

A 50-ton crane would be sufficient to handle the transformer if shipped in oil, as the transformer could be withdrawn from the oil on site, the tank with oil

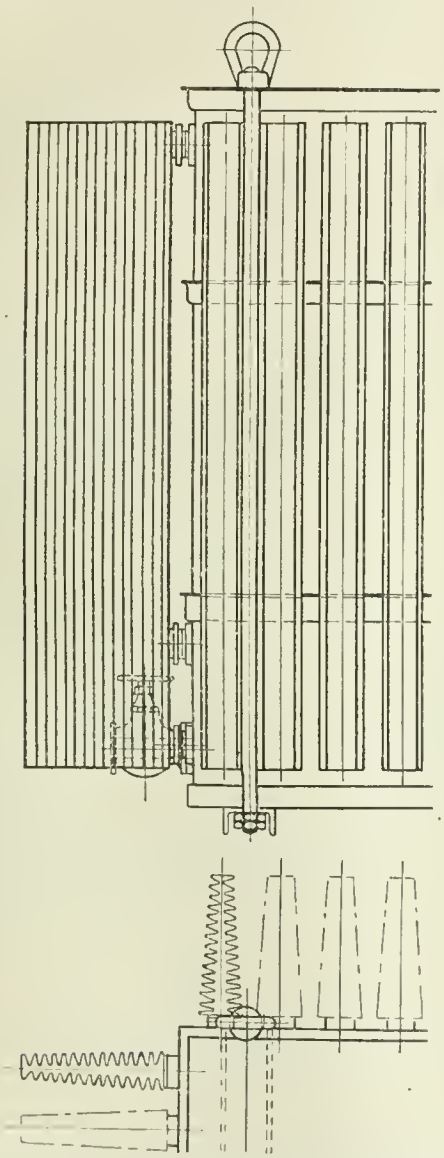


FIG. 3.—Outline of tank with external detachable radiating pockets for 7,000-k.v.a. three-phase 50-period oil-immersed self-cooled transformer.

Approximate overall dimensions:
Length 12 ft., breadth 8 ft., height 12 ft.

lifted off the truck and placed in position, and the transformer then lifted back into the oil.

These operations, in a properly designed station, would not occupy more than a few hours, during which time the transformer windings would not absorb any appreciable moisture and full advantage would thus be taken of drying out in the factory before shipment.

The use of such large units is only possible in a well-designed station with a properly laid-out transformer house having sufficient headroom.

The overall height of a 40,000-k.v.a. three-phase transformer would be about 11 feet 6 inches (excluding terminals), and thus about 28 feet total headroom from crane hook to floor would be required.

Where sufficient handling facilities are not available, smaller three-phase units would have to be used, or a group of three single-phase units each of one-third the group capacity. The largest single-phase transformer that could be shipped complete in oil within the prescribed dimensions is also limited to a certain extent by the shape of the transformer carcase, as determined by technical designing considerations. Actually the limiting single-phase rating is about 25,000 k.v.a. at 50 cycles and 50,000 volts.

The weights of such a transformer would be approximately:—

| | |
|---|---|
| Transformer .. .. | 23 tons |
| Tank.. .. .. .. | 6 ,, |
| Oil .. .. .. .. | 8 ,, |
| Complete with oil .. .. | 37 ,, |

### TRANSFORMERS SHIPPED DISMANTLED.

For transformers which are shipped dismantled and erected on site the limiting ratings given above for the different types under (*a*), (*b*), and (*c*) can be further increased.

(*a*) *Oil-immersed self-cooled type.*—For three-phase transformers the limits are the same as when shipped complete, since the tank must be put on the truck standing upright. In the case of single-phase transformers, however, large self-cooling tanks can be transported laid on their side. The limiting ratings may thus be increased by about 25 per cent, i.e. to about 3,750 k.v.a. at 50 cycles, and 2,500 k.v.a. at 25 cycles up to 50,000 volts. These can be still further increased by resorting to a construction of self-cooling tank with detachable radiating pockets.

This type of tank is widely used in America and is illustrated in Fig. 3. The tank is shipped with the external radiators dismantled so far as this is necessary to meet the loading gauge limits, and the radiators are attached to the tank on site.

By using such tanks the limiting single-phase rating would be increased, over transformers shipped complete, to about 6,000 k.v.a. at 50 cycles, and 4,000 k.v.a. at 25 cycles. For three-phase transformers in this type of tank the limits would be approximately 7,000 k.v.a. at 50 periods and 5,000 k.v.a. at 25 periods.

(*b*) *Oil-immersed water-cooled type.*—In this case there is no gain in the three-phase limiting rating in shipping dismantled, as the output is restricted to about 15,000 k.v.a., 50 periods, by the size of the cooling coil.

The single-phase limit may be increased by about 50 per cent, i.e. to 15,000 k.v.a., 50 periods, if the tank is transported on its side or constructed in two sections built up together on site.

(*c*) *Oil-immersed forced-cooled type.*—By shipping the

* A turbo-generator set for 40,000 kw. 1,000 r.p.m. would require a crane of 100 tons to handle the heaviest parts of the plant.

transformer dismantled and the tank in two or more sections the possible output is limited only by the crane capacity.

From the manufacturing standpoint any size of transformer can be constructed that is likely to be called for with the largest generating units. The individual parts can be easily handled and the possible output is only limited by the crane on site, which must be sufficiently large to lift the transformer, when

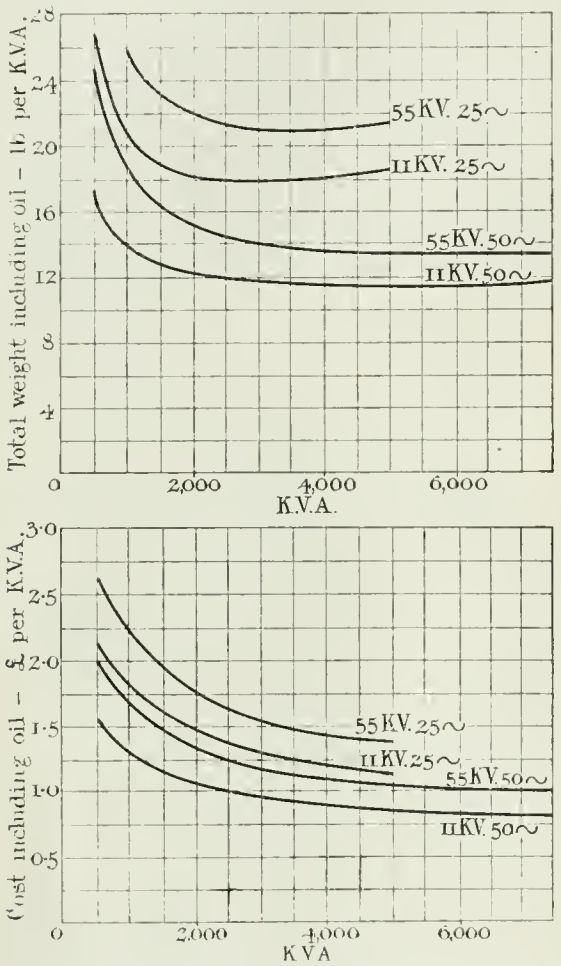



FIG. 4*a*.—Curves of approximate weight and price per k.v.a. rated output for three-phase oil-immersed self-cooled transformers.

erected, into its tank. Assuming a 50-ton crane, the limiting rating for a three-phase 50,000-volt transformer would be about 50,000 k.v.a. at 50 cycles, and 25,000 k.v.a. at 25 cycles.

The above figures are summarized in Table 1, where are also given approximate weights and dimensions. These data are based on, and developed from, the designs of the largest transformers that have actually been made. It should, however, be borne in mind that all data are approximate and are here set together for guidance in making preliminary designs and estimates for large power stations such as are now under consideration for this country.

### (3) Price and Weight.

The principal factors which influence the price and weight of transformer units are:—

(*a*) Whether single or three-phase.
(*b*) Frequency.
(*c*) Voltage.
(*d*) Method of cooling.

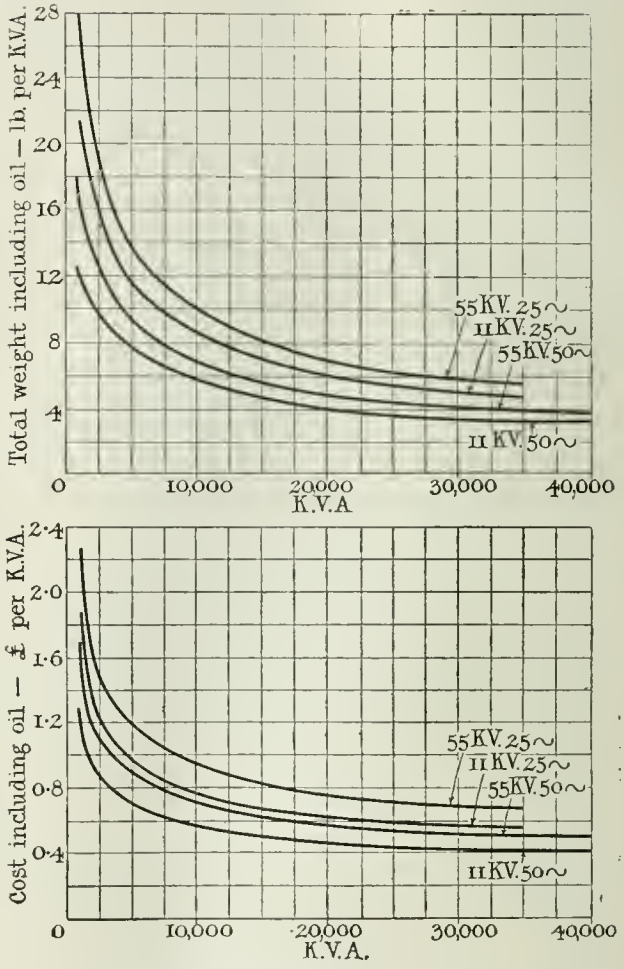



FIG. 4*b*.—Curves of approximate weight and price per k.v.a. rated output for three-phase oil-immersed, water- and forced-cooled transformers.

Other and less fundamental considerations are questions of temperature rise, overload capacity, and special structural requirements.

In Figs. 4*a* and 4*b* have been brought together typical representative curves of price and weight per k.v.a., showing the influence of the four variables, (*a*), (*b*), (*c*), and (*d*) above. These curves are all based on the British Standard Rating,* viz. 50 degrees C. temperature rise in oil, with 40° C. air temperature and no overload capacity at this air temperature.

The curves are naturally approximate and are intended to serve as a comparative basis for preliminary

* See B.E.S.A. Report, No. 72, of 1917.

estimates of large installations. While they are self-explanatory a few general observations may be helpful :—

(*a*) *Single* v. *three-phase.*—In general a large single-phase transformer is about 7 to 10 per cent cheaper and about 12 to 15 per cent lighter than a three-phase transformer of the same rating. A large three-phase transformer is, however, about 5 to 8 per cent cheaper and 10 to 15 per cent lighter than a group of three single-phase transformers of the same three-phase group capacity. This matter is dealt with further in Section (4) below.

(*b*) *Frequency.*—On the average, large 25-cycle transformers are some 35 per cent dearer and 40 per cent heavier than 50-cycle transformers of the same rating.

(*c*) *Voltage.*—The curves are shown for two high-tension voltages, viz. 11,000 and 55,000 volts, and for a maximum low-tension voltage of 6,000 volts. Data for other high-tension voltages may be interpolated or exterpolated. As a rough guide it may generally be taken that the price and weight increase by 1 per cent for the smaller ratings, down to 0·6 per cent for the largest ratings, per 1,000 volts normal pressure above 11,000 volts.

The influence of the voltage is greater the lower the rated output, as the frames are smaller and the copper factor of the windings decreases more rapidly with increasing voltage.

(*d*) *System of cooling.*—The curves shown all refer to oil-immersed transformers, self-cooled up to the practicable limits of rated output (see Table 1) and water-cooled or forced-cooled (with external oil circulation) for all rated outputs up to the maximum figures given in Section (2). At 1,000 k.v.a., 50 periods, the present-day prices of the self-cooled and water-cooled types are not appreciably different; the larger self-cooled units are, however, appreciably dearer than water cooled, up to a difference of 15 to 20 per cent.

TABLE 1.

*Limiting Ratings of Oil-immersed Transformers up to 50,000 Volts.*

| Cooling | Shipment | Phase | Periods | Limiting Rated Output | Approximate Total Weight Complete with Oil | Approximate Overall Dimensions L | B | H† | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | k.v.a. | tons | ft. | ft. | ft | |
| Self-cooled | Complete in oil | 1 | 50 | 3,000 | 17 | 6 | 5 | 12 | Tanks built for shipment complete in one piece |
| | | | 25 | 2,000 | 20 | | | | |
| | | 3 | 50 | 5,000 | 30 | 9 | 5 | 12 | |
| | | | 25 | 3,500 | 33 | | | | |
| | Transformer and tank separately | 1 | 50 | 6,000 | 30 | 11 | 9 | 12 | Tanks with detachable external radiators |
| | | | 25 | 4,000 | 32 | | | | |
| | | 3 | 50 | 7,000 | 42 | 12 | 8 | 12 | |
| | | | 25 | 5,000 | 48 | | | | |
| Water-cooled or forced cooled * | Complete in oil or dismantled | 1 | 50 | 10,000 | 26 | $6\frac{1}{2}$ | $5\frac{1}{2}$ | 12 | |
| | | | 25 | 6,500 | 30 | | | | |
| | | 3 | 50 | 15,000 | 42 | 10 | $5\frac{1}{2}$ | 12 | |
| | | | 25 | 10,000 | 45 | | | | |
| Forced cooled only * | Complete in oil | 1 | 50 | 25,000 | 37 | 9 | 7 | 13 | Limiting ratings for 50-ton crane to handle heaviest part |
| | | | 25 | 12,500 | 40 | | | | |
| | | 3 | 50 | 40,000 | 58 | 14 | 7 | 13 | |
| | | | 25 | 20,000 | 58 | | | | |
| | Dismantled | 1 | 50 | 35,000 | 50 | 10 | 8 | 14 | |
| | | | 25 | 17,500 | 50 | | | | |
| | | 3 | 50 | 50,000 | 70 | 15 | 8 | 14 | |
| | | | 25 | 25,000 | 70 | | | | |

* Weights include oil coolers for forced cooled transformers. † H = Height over terminals.

This may be to some extent offset in certain cases by the cost of water, pumping, storage, etc., which is referred to again in Section (4).

## (4) Choice of Type.

(*a*) *Cooling.*—The system of cooling adopted is determined largely by considerations of the size of unit involved and the situation and cooling facilities available. For units of capacity up to the limiting sizes of self-cooled transformers given in Section (2), the following broad lines may be laid down.

For isolated substations where continual attendance is not available, self-cooled units are naturally to be

recommended up to 5,000 k.v.a. three-phase and 3,000 k.v.a. single-phase at 50 cycles.

The same rule would apply for substations with continual attendance where cooling water is dear and for power stations where this is also the case.

There is a decided tendency nowadays towards large self-cooled units for substations and, in designing such substations, the following points should be borne in mind:—

Particular attention should be paid to ventilating the transformer chambers so that the heat generated by the losses can be dissipated without the air temperature being unduly raised (not above a temperature of 25° C. if possible). Ample headroom should be provided above the transformer, and good clearances should be allowed between the tank and any adjacent wall or cubicle. This latter should not be less than 1 to 2 feet up to 1,000 k.v.a., and 2 to 3 feet for larger sizes.

The substation or cubicles should be provided with ample air ingress and egress to ensure sufficient circulation. The quantity of air should be approximately 200 cubic feet per minute per kilowatt loss for a temperature rise of air of about 10 degrees C.

In the case of fireproof cubicles the ventilating apertures might be fitted with automatic dampers which would close at a set maximum temperature such as would be attained in case of fire; a figure of 150° C. would suffice.

In power stations or substations with attendance, where a plentiful and cheap water supply is available, water-cooled units are generally recommended for outputs above the following:—

| | | | |
|---|---|---|---|
| 2,500 | k.v.a. | three-phase | 50 cycles |
| 1,700 | ,, | ,, | 25 ,, |
| 1,500 | ,, | single-phase | 50 ,, |
| 1,000 | ,, | ,, | 25 ,, |

This is based on questions of capital cost, floor space, headroom, and heating of surrounding air due to losses, all of which are more favourable with water-cooling.

Although water-cooled transformers (with internal cooling coils) can be built in very large sizes [see Section (2)], forced cooling with external oil circulation is to be recommended above the following limits:—

| | | | |
|---|---|---|---|
| 5,000 | k.v.a. | three-phase | 50 cycles |
| 3,500 | ,, | ,, | 25 ,, |
| 3,500 | ,, | single-phase | 50 ,, |
| 2,500 | ,, | ,, | 25 ,, |

There are several advantages pertaining to this system of cooling, viz. better oil circulation is obtained in the transformer, which ensures a more uniform cooling of the windings; smaller headroom is required, which may be of importance in large units; several transformers may be cooled by a common cooler; less risk of water getting into the oil as the pressure of the oil in the cooler is maintained higher than that of the water.

The oil circulation required is 0·66 gallon per minute per kilowatt loss for 15 degrees C. fall in temperature of the oil, or 1 gallon per minute per kilowatt for 10 degrees C. fall.

In moderate-sized units where the choice lies between self-cooling and water-cooling the question of capital cost will enter. As is seen in Section (3), the water-cooled type is generally cheaper than the self-cooled, but the interest on the saving in capital outlay must be set off against the annual cost of cooling water. In large installations where water is scarce and dear a reservoir and water-cooling plant may profitably be installed.

It is impracticable to particularize further, as individual circumstances largely affect the choice of type of cooling. Nevertheless, the above general considerations in this matter may be helpful.

Where the space available is limited, water-cooled or forced-cooled units offer the advantage of better space economy. If, however, in such cases water is not available or is dear, recourse must be had to air-blast cooling with either oil-immersed or dry-type transformers.

In the former type the air-blast is directed on to the corrugated tank, which is usually surrounded by a shield for this purpose. By these means an increase of output of about 30 per cent over a self-cooled transformer of the same dimensions can be obtained.

The use of the latter type (dry type) is limited by the voltage and is generally not to be recommended for voltages above 20,000 volts on account of the insulation question, although this type has been successfully built for higher voltages in dry climates.

Where air-blast transformers of either type are installed, continual attendance is necessary, as the ventilating fans must be kept running.

(*b*) *Single* v. *three-phase*.—The question of the relative merits of single and three-phase transformers for three-phase groups has often been discussed. There is no specific rule which can be formulated, as the choice depends almost entirely on local conditions in each case. The authors wish here to indicate the principal considerations affecting the choice in this matter, in light of present-day practice in transformer manufacture and operation.

Apart from the relative merits of core and shell type dealt with in Section (6), the principal factors affecting the choice of single-phase or three-phase units are capital cost, floor space, spares, and continuity of supply.

In general, where a number of groups are installed three-phase units will be more suitable, and where few groups are installed single-phase are preferable. In the latter case single-phase units ensure greater reliability of supply, as a group of three single-phase transformers operating in delta-delta can still run at about 58 per cent of the group output with two of the transformers in open delta, should one transformer fail and be cut out.

Such an arrangement is convenient if only one or two three-phase groups are installed, and in this case only one single-phase spare need be carried.

These will usually be the conditions in small and medium substations where continuity of supply is of greater importance than floor space.

*Central stations and large substations.*—In large substations and central stations where the number of units installed may be three or more, three-phase units, within the limitations given in Section (2), will in general be preferable.

In very large stations where the rated output of the generating units is of the order 30,000 to 40,000 k.v.a., although three-phase transformers would be practicable, the question will often be determined by considerations of handling, which may necessitate the use of single-phase units (see Figs. 5 and 6).

If a number of three-phase units are installed, one complete three-phase transformer can be carried as a spare, without an undue increase in the capital cost.

From the above tabulation all the necessary comparisons may be drawn.

It may be noted that the maximum lifting weight of transformer and tank complete for the three-phase units is 55 tons, and a crane capacity to meet this would be required if three-phase units were installed.

At 50 cycles the above transformers would be capable of a rated output of about 45,000 k.v.a. per group.

Data for the losses, efficiencies, and cooling for such a 50-period group are given in Table 3.

The above units may be regarded as typical of what is rapidly becoming modern practice in this country.

In such a station with, say, 10 generating units for a total plant capacity of about 250,000 k.v.a. at 25 periods, or 450,000 k.v.a. at 50 periods, the total cost of transformers required, excluding spares, would be approximately $30 \times £6,500 = £195,000$ for single-phase, or $10 \times £18,500 = £185,000$ for three-phase.

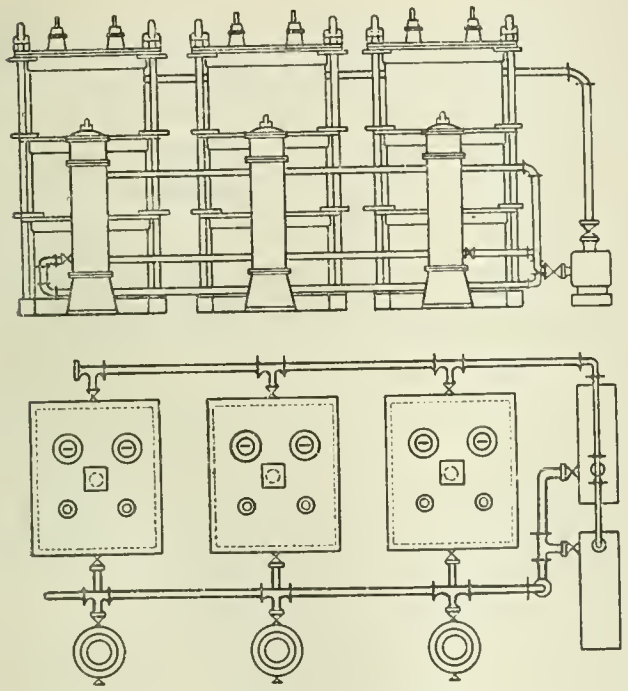


Fig. 5.—Outline of group of three 7,800-k.v.a. 25-period single-phase transformers.

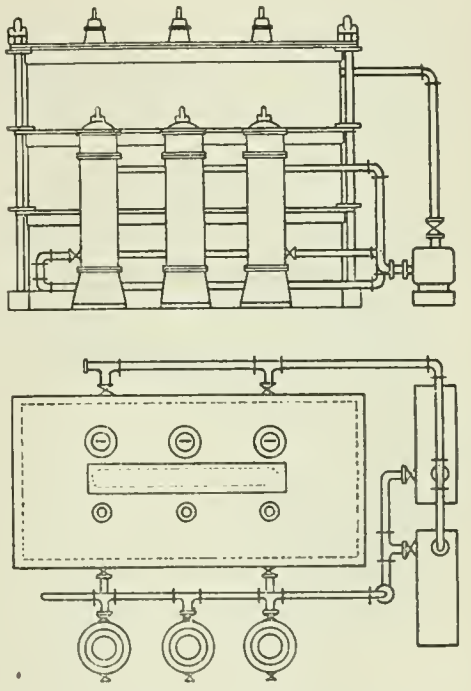


Fig. 6.—Outline of 23,400-k.v.a 25-period three-phase transformer.

The floor space occupied by the transformers will be appreciably less than for single-phase groups, a consideration which is of some importance in very large stations where the space occupied by the generating units is relatively not large.

A three-phase unit has a slightly higher efficiency than a group of single three-phase transformers of the same group output, but the difference is hardly worth considering.

In illustration of the above considerations we give in Table 2 a comparison of a single-phase and three-phase group for 23,400-k.v.a. 25-cycle 6,500/20,000 volts. Thirteen of these 7,800-k.v.a. (British Standard Rating) single-phase transformers, designed by one of the authors, were recently built for the Glasgow Corporation's Dalmarnock power station.

Drawings of the general outline of transformers and cooling arrangements are shown in Figs. 5 and 6 for the three-phase and single-phase groups respectively.

If single-phase groups were employed, one single-phase transformer per six transformers installed (i.e. for every two three-phase groups) would suffice as spare.

The total cost of spares would be thus:—

$$5 \times £6,500 = £32,500.$$

If three-phase units were used, one complete three-phase transformer for every five or six transformers installed would meet the case.

The cost of spares in this case would be

$$2 \times £18,500 = £37,000.$$

TABLE 2.

*Comparison of 23,400-k.v.a. three-phase and three 7,800-k.v.a. single-phase 25-period Transformer Groups.*

| | | |
|---|---|---|
| Phase | three-phase | 3 single-phase |
| Frequency | 25 cycles | 25 cycles |
| Group output | 23,400 k.v.a. | $3 \times 7{,}800 = 23{,}400$ k.v.a. |
| *Weights and Price* (excluding coolers). | | |
| Weight of transformer | $38\frac{1}{2}$ tons | $3 \times 14 = 42$ tons |
| ,, tank | $5\frac{1}{2}$ tons | $3 \times 2\frac{3}{4} = 8\frac{1}{4}$ tons |
| Oil quantity | 3,200 gallons | $3 \times 1{,}300 = 3{,}900$ gallons |
| Total weight complete with oil (excluding coolers) | 55 tons | $3 \times 22 = 66$ tons |
| Approximate price complete with oil | £18,500 | $3 \times$ £6,500 = £19,500 |
| Price per k.v.a. | 15·8s. | 16·7s. |
| Weight per k.v.a. | 5·45 lb. | 6·37 lb |
| *Losses and Efficiency.* | | |
| Iron loss | 52 kw. | $3 \times 20 = 60$ kw. |
| Copper loss at 15° C. | 202·5 | $3 \times 67{\cdot}5 = 202{\cdot}5$ kw. |
| Total losses at 15° C. | 254·5 | $3 \times 87{\cdot}5 = 262{\cdot}5$ kw. |
| Efficiency, full load | 98·92 per cent | 98·89 per cent |
| ,, three-quarter load | 99·06 ,, | 99·02 ,, |
| ,, one-half load | 99·13 ,, | 99·06 ,, |
| *Cooling* (3 coolers per transformer group). | | |
| Oil circulation, gallons per minute | 180 | 185 |
| Water circulation, gallons per minute, at 10° C. | 90 | 92·5 |
| Temperature rise in oil | 50 degrees C. | 50 degrees C. |
| Difference in oil temperature entering and leaving | 10 ,, | 10 ,, |
| Difference in rise in water | 9 ,, | 9 ,, |
| Oil pump | 10 h.p. | 10 h.p. |
| Pressure in coolers | 30 lb. | 30 lb. |
| *Dimensions.* | | |
| Overall length | 13 ft. 3 in. | 6 ft. 9 in. } per single- |
| ,, breadth | 7 ft. 3 in. | 6 ft. 3 in. } phase trans- |
| ,, height | 12 ft. 6 in. | 12 ft. 6 in. } former |
| Headroom to crane hook | 23 ft. 0 in. | 23 ft. 0 in. |
| Outline sketch | See Fig. 5 | See Fig. 6 |

TABLE 3.

*Comparison of 45,000-k.v.a. three-phase and three 15,000-k.v.a. single-phase 50-period Transformer Groups.*

| | | |
|---|---|---|
| Phase | three-phase | 3 single-phase |
| Frequency | 50 cycles | 50 cycles |
| Group output | 45,000 k.v.a. | $3 \times 15{,}000 = 45{,}000$ k.v.a. |
| *Losses and Efficiency.* | | |
| Iron loss | 117 kw. | $3 \times 45 = 135$ kw. |
| Copper loss at 15° C. | 210 kw. | $3 \times 70 = 210$ kw. |
| Total losses at 15° C. | 327 kw. | $3 \times 115 = 345$ kw. |
| Efficiency, full load | 99·28 per cent | 99·24 per cent |
| ,, three-quarter load | 99·31 ,, | 99·25 ,, |
| ,, one-half load | 99·25 ,, | 99·17 ,, |
| *Cooling.* | | |
| Oil circulation, gallons per minute | 200 | 215 |
| Water circulation, gallons per minute at 10° C. | 100 | 108 |
| Temperature rise in oil | 50 degrees C. | 50 degrees C. |
| Difference in oil temperature entering and leaving | 13 ,, | 13 ,, |
| Temperature rise in water | 11·5 ,, | 11·5 ,, |
| Oil pump h.p. | 15 | 15 |
| Pressure in cooler | 30 lb. | 30 lb. |

N.B.—All weights and dimensions are the same as those given in Table 2 for 23,400-k.v.a. 25-period groups.

In this connection the advantage of single-phase units lies in the flexibility of the spares.

*Medium and small substations.*—In substations of small and medium plant capacity up to, say, 5,000 k.v.a. it will not generally be economical to install more than two or three groups.

In such cases, taking all things into consideration, the choice tends towards single-phase units of medium capacity, forming one or two three-phase groups, with one single-phase transformer as spare for the substation.

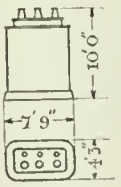
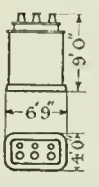
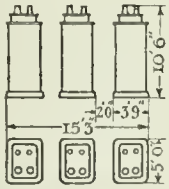
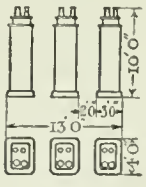
The considerations leading to this opinion are illustrated by the typical example of a 3,000-k.v.a. 20,000-volt 50-cycle substation, for which data of four different possibilities are given in Table 4.

The above comparison is based on core-type three-phase and shell-type single-phase transformers, the relative merits of which are discussed in Section (5).

From the Table it will be seen that the most satisfactory proposition, (*c*), is three single-phase 1,000-k.v.a. units with one spare. The capital cost is the least of all four propositions, the total floor space required is about the same as (*a*) and less than in (*b*) and (*d*), and the efficiency is rather better.

TABLE 4.

*Comparison of Single-phase and Three-phase Transformers for 3,000-k.v.a. 20,000-volt 50-period Substation.*

| | *a* | *b* | *c* | *d* |
|---|---|---|---|---|
| | Three-phase Units | | Single-phase Units | |
| Number and k.v.a. of units | 2 at 1,500 k.v.a. | 3 at 1,000 k.v.a. | 3 at 1,000 k.v.a. | 6 at 500 k.v.a. |
| Spares | 1 at 1,500 k.v.a. | 1 at 1,000 k.v.a. | 1 at 1,000 k.v.a. | 1 at 500 k.v.a. |
| *Weights and Price.* | | | | |
| Weight of transformer, lb. | 11,000 | 8,000 | 6,000 | 3,500 |
| Weight of tank, lb. | 6,500 | 5,000 | 4,000 | 2,200 |
| Oil, gallons | 800 | 400 | 480 | 350 |
| Total weight, complete, lb. | 17,500 | 13,000 | 10,000 | 5,700 |
| Total weight, complete, with oil, lb. | 24,700 | 16,600 | 14,300 | 8,850 |
| Approximate price complete with oil | £1,840 | £1,400 | £1,200 | £750 |
| Total cost of all transformers | £5,520 | £5,600 | £4,800 | £5,250 |
| Price per k.v.a. | 24s. 6d. | 28s. | 24s. | 30s. |
| *Losses and Efficiency* (per three-phase group). | | | | |
| Iron loss | 10 kw. | 7 kw. | 3 × 5 = 15 kw. | 3 × 3·3 = 9·9 kw. |
| Copper loss at 15° C. | 10 kw. | 7 kw. | 3 × 6·5 = 19·5 | 3 × 4·2 = 12·6 kw. |
| Total losses at 15° C. | 20 kw. | 14 kw. | 3 × 11·5 = 34·5 kw. | 3 × 7·5 = 22·5 kw. |
| Efficiency, full load | 98·7 per cent | 98·67 per cent | 98·86 per cent | 98·52 per cent |
| ,, three-quarter load | 98·65 ,, | 98·57 ,, | 98·85 ,, | 98·51 ,, |
| ,, one-half load | 98·38 ,, | 98·27 ,, | 98·69 ,, | 98·28 ,, |
| *Dimensions of Three-phase Group.* | | | | |
| Overall length | 7 ft. 9 in. | 6 ft. 9 in. | 15 ft. 3 in. | 13 ft. 0 in. |
| ,, breadth | 4 ft. 3 in. | 4 ft. 0 in. | 5 ft. 0 in. | 4 ft. 0 in. |
| ,, height | 10 ft. 0 in. | 9 ft. 0 in. | 10 ft. 6 in. | 10 ft. 0 in. |
| Headroom to crane hook | 18 ft. 0 in. | 17 ft. 0 in. | 18 ft. 6 in. | 18 ft. 0 in. |
| Outline sketch to scale |  |  |  |  |

In any of these propositions the transformers can be designed with the same proportion of iron and copper loss to suit the load factor; this matter is dealt with below.

(5) PROPORTION OF LOSSES AND OVERLOAD CAPACITY.

(*a*) *Power station transformers.*—In large step-up transformers for power stations, which are practically

always working near or at full load, the actual ratio of iron to copper loss is itself unimportant. The average continuous load on such transformers in an economically run station is from ¾ load to full load on any sets in commission.

A transformer designed for maximum efficiency has the iron loss about equal to the copper loss, which condition should be thus fulfilled at ¾ load to full load.

In 40- to 60-period transformers the most economical and sound design usually fulfils this condition.

In 25-period transformers, as the loss in iron decreases practically in proportion to the frequency, the iron loss is usually lower and of the order one-half to one-third of the copper loss.

It is possible to design a 25-period transformer for any ratio of iron to copper loss, within reasonable limits, but the normal design usually meets the requirements of the general run of power stations.

Mention should be made here of the overload capacity of large power-station transformers of the water-cooled and forced-cooled types. The overloads specified for such step-up units should correspond to the generator overloads.

Obviously the lower the load factor the lower should be the iron losses compared with the copper losses, and vice versa.

An illustration of the method of arriving at the best proportion for the case of a load diagram similar to that in Fig. 8 is set forth in Table 5.

The above case is typical and shows clearly that where the load factor is high the ratio of iron to copper loss is of little importance. Similar considerations must be made for each individual case, where the nature of the load is known.

*Overload capacity in relation to proportionate losses.*—In cases where specified overloads are required, these conditions must be taken into account in conjunction with economical considerations in settling the most suitable proportions of iron and copper loss.

It has been and is still widely the practice in this country to specify definite overloads for stated periods of time. It is, however, becoming more usual to adopt the British Standard Rating, which is the maximum continuous rating and includes any long-period overloads required.

On the basis of the British Standard Rating no overloads are permitted, the rating being the maximum for 50 degrees C. temperature rise in oil, at 40° C. air temperature, giving a maximum oil temperature of 90° C., which is the safe working limit.

Any transformer rated on this basis can, however, withstand overloads for short periods, starting with the transformer at a temperature in oil below the maximum of 90° C., even with 40° C. air temperature.

Such a transformer can also support an overload continuously if working in such surroundings that the air temperature is less than the British Standard maximum figure of 40° C. Such an overload rating exceeds the British Standard Rating and might possibly subject the windings to excessive and dangerous temperatures, even though the British Standard limiting temperature of 90° C. in the oil were not exceeded.

Where the plant is not ordered and rated on the British Standard basis it is customary to call for a lower temperature rise of 40 or 45 degrees C., which allows for specified overloads.

It is, however, very desirable to rate all plant on the same temperature basis, and it is to be hoped that the British Standard Rating will be generally adopted.* In specifying transformers this will only involve the inclusion of the overload in the nominal rating, and

TABLE 5.

*Annual Charges for Losses for Different Ratios of Iron to Copper Loss for Average Load* 1,400 *k.v.a., Peak Load* 2,000 *k.v.a., Normal Rating* 1,500 *k.v.a.*

| | | | | |
|---|---|---|---|---|
| Ratio of iron to copper loss | 1 : 1 | 1 : 1·15 | 1 : 1·5 | 1 : 2 |
| Efficiency at 1,400 k.v.a | 99·0 | 99·0 | 99·01 | 99·02 |
| ,, 1,500 k.v.a. | 99·0 | 99·0 | 99·0 | 99·0 |
| Iron loss, watts | 7,500 | 7,000 | 6,000 | 5,000 |
| Copper loss, watts at 1,400 k.v.a. | 6,500 | 7,000 | 7,800 | 8,700 |
| ,, watts at 1,500 k.v.a. | 7,500 | 8,000 | 9,000 | 10,000 |
| Annual charge for losses at ⅜d. per unit | £193 | £193 | £189·5 | £188·5 |

If the generators are specified to withstand, say, 25 per cent overload for 2 hours or more, transformers of the water-cooled and forced-cooled type would require to be designed to stand this overload continuously, since such transformers rapidly reach their final steady temperature. This is shown in the comparative curves in Fig. 7.

The point to be noted is that on such artificially cooled plant it is inconsistent to specify short time overloads, as the plant for such overloads will generally have to be designed to stand the overload continuously.

It is desirable to rate such plant on the maximum continuous rating, as specified in the B.E.S.A. Report, so that both generators and transformers are capable of the same duty.

(*b*) *Substation transformers.*—In substations the most economical proportion of iron to copper loss depends on the load factor of the individual substation and no specific rule can be laid down. The load curves on loads of different natures are very divergent, as is seen in the actual load diagrams in Figs. 8, 9, 10, and 11.

In general, if the load diagram is known or can be predetermined to a fair degree of accuracy, the ratio of iron to copper loss should be so chosen as to give a maximum all-year efficiency.

* See B.E.S.A. Report, No. 72, of 1917.

it is then much easier to compare transformers on this common basis.

When considering the maximum rating or overload, in cases where the load factor is low the copper loss should be decreased relatively to the iron loss, so that the copper will not be unduly heated and the total temperature rise not excessive on the heavy overload.

For example, consider a substation with two 1,000-k.v.a. groups installed running at an average load factor of 70 per cent. In such a case it is sometimes specified that either group should be able to supply the average load of the two groups in the event of failure of one of them. The load on the one group would then be 1,400 k.v.a., i.e. equivalent to a continuous overload of 40 per cent.

If a temperature rise of 40 degrees C. in oil at normal load, and 60 degrees C. in oil at 40 per cent continuous overload, were specified, the ratio of iron to copper loss at normal load to meet these requirements must be 1 : 1, or on an average load of 70 per cent, 1 : 0·49. Thus the transformers would necessarily have a relatively high iron loss, which would be uneconomical from the point of view of standing charges for losses. Such an overload will only occur rarely, as an emergency measure, and it would doubtless be more economical to install transformers with a better ratio of losses, say, iron to copper loss 1 : 1·4. With this ratio, for 60 degrees C. temperature rise in oil on 40 per cent overload, the temperature rise at normal load would only be about 38 degrees C.

It is important to bear these points in mind when specifying temperature rise on a heavy overload. Unless this bears the right relation to the normal temperature rise an uneconomical transformer may often result as a direct consequence.

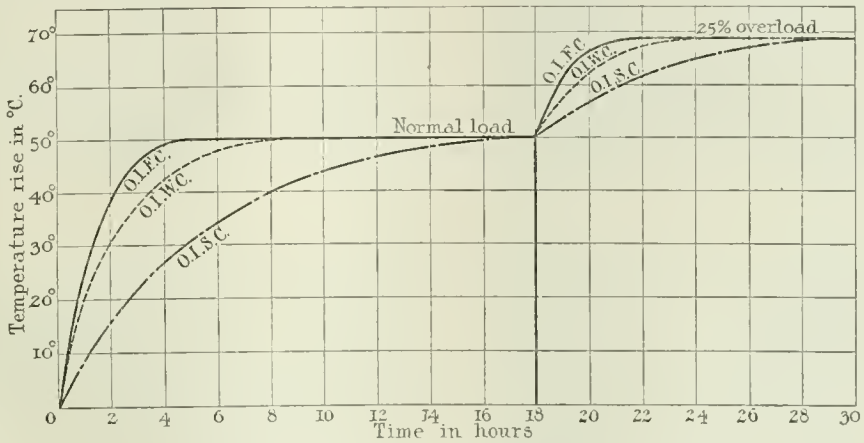



FIG. 7.—Typical temperature curves for 4,000-k.v.a. transformers.
O.I.S.C. = Oil-immersed self-cooled.
O.I.W.C. = Oil-immersed water-cooled.
O.I.F.C. = Oil-immersed forced-cooled.
Ratio of copper loss to iron loss = 2 : 1.

### (6) Comparison of Core and Shell Types.

The relative merits of core and shell-type transformers have frequently been the subject of discussion. In approaching this question such discussion is usually prejudiced by the particular views and experience of individual manufacturers and power-supply engineers.

From the manufacturer's point of view both types can be satisfactorily built in either single-phase or three-phase. But the types recommended by individual manufacturers depend largely on their experience and manufacturing facilities.

In this connection it is of interest to note the general practice (as far as is known) of the leading British, American, and Continental firms.

(*a*) *British.*
Berry—Circular shell type.
Brush—Core type.
Ferranti—Core type and shell type.
Johnson & Phillips—Core type
Westinghouse—Shell type, single-phase.
Core type, three-phase.

(*b*) *American.*
General Electric Co.—Core type (formerly shell).
Westinghouse—Shell type.

(*c*) *Continental.*
A.E.G.—Core type.
Allmana Svenska—Core type (rectangular section).
Brown-Boveri—Core type.
Oerlikon—Core type (rectangular section).
Siemens Schuckert—Shell type.

The general manufacturing considerations which influence this question are summarized briefly in the following notes :—

*Core type.*—This type as usually constructed has cruciform-section cores and circular coils. In this respect it lends itself better to small and high-tension units, as small conductors can be better wound in circular coils and the insulating problem is simplified.

For medium size units the three-phase core type makes a satisfactory job, but in very large units the bracing and cooling become quite a problem.

In large units it will generally be preferable to split

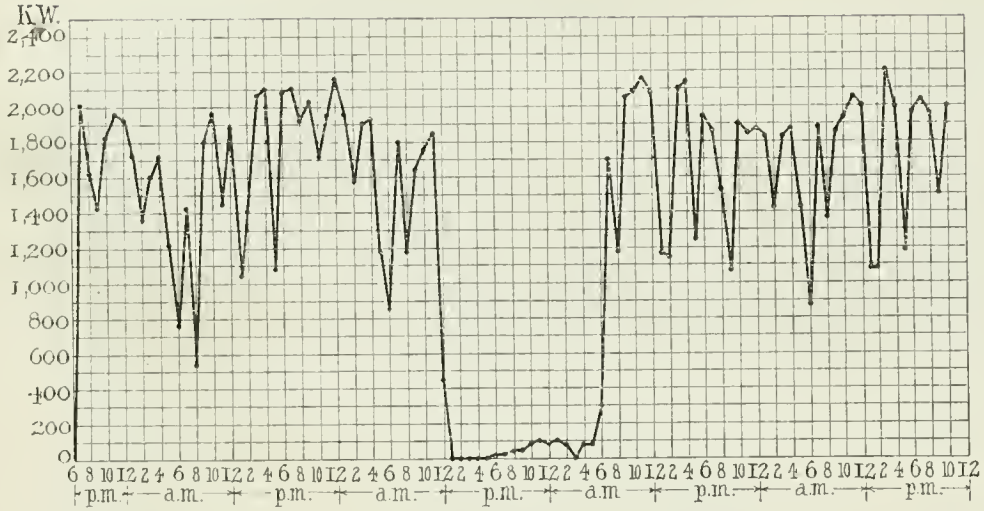



FIG. 8.—Substation load curve—mixed load; power factor approx. 0·8.

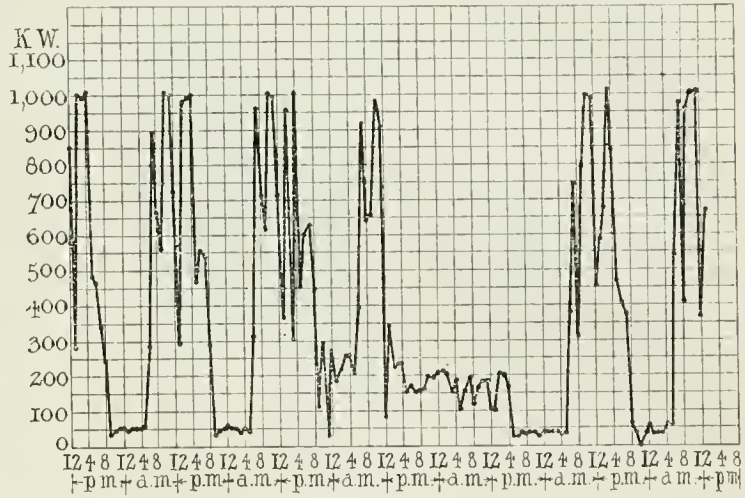



FIG. 9.—Substation load curve—shipyard load; power factor approx. 0·8.

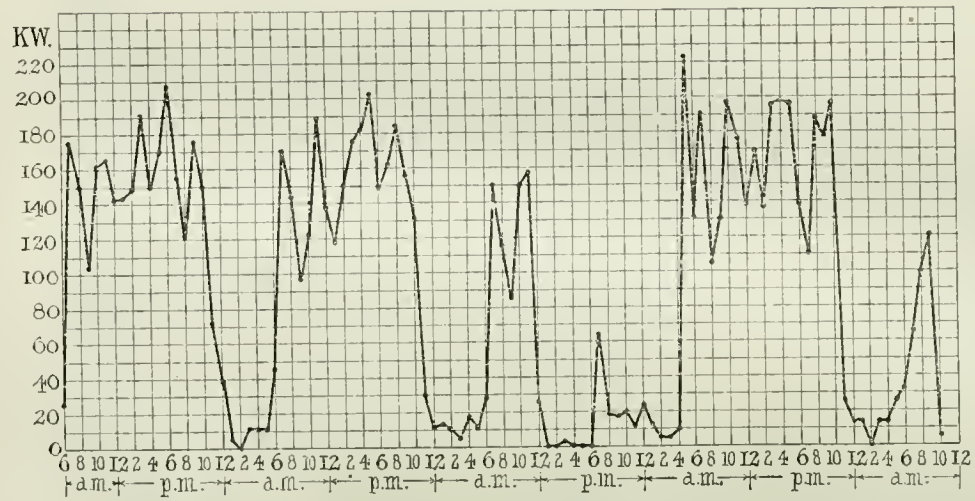



FIG. 10.—Substation load curve—winder; power factor approx. 0·62.

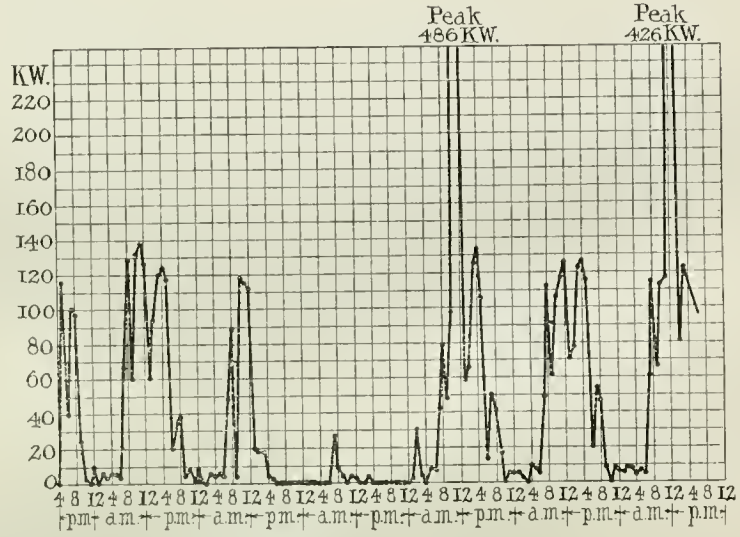



FIG. 11.—Substation load curve—dry dock pumping and general load; power factor approx. 0·8.

up into three single-phase units forming a three-phase group.

The latter can be more conveniently handled and the windings more efficiently braced and ventilated.

*Shell type.*—This type as usually constructed has rectangular coils with core punchings assembled around them with lap joints. The shell type is generally preferable for single-phase units except for small sizes at high voltage. The construction is simpler, more robust, and less liable to damage in handling and transport.

The windings can be very rigidly braced, and the construction gives very large cooling surfaces of windings and core.

Regarding electrical performance, there is little to choose between the two types for the same amount of active copper and iron. Also for the same electrical performance there is little difference in cost.

From the standpoint of service requirements the principal considerations relate to shrinkage of windings, coil bracing, insulation, robustness, and ability to withstand short-circuits. These points are discussed below :—

*Shrinkage—due to contraction of insulation.*—The core-type windings are in general more liable to shrinkage, as the weight of the copper in the coils always bears directly on the insulation, hence the insulation is always under a permanent compressive stress. This is not so aggravated in the case of single-layer spiral windings of copper strip wound on edge, where the shrinkage is practicably negligible on account of the relatively small thicknesses of insulation between turns as compared with the insulation between coils in section-wound or coil-wound transformers. In the latter type of winding the total shrinkage after 12 months in general service may be of the order of $2\frac{1}{2}$ per cent, i.e. 1 inch in 40 inches of winding length for a 20,000-volt transformer.

Comparing this with shell-type transformers, in this type the shrinkage is practically nil because, in spite of the large amount of insulation, the dead weight of the copper in the coils exerts no pressure on the insulation in the usual construction (see Fig. 12).

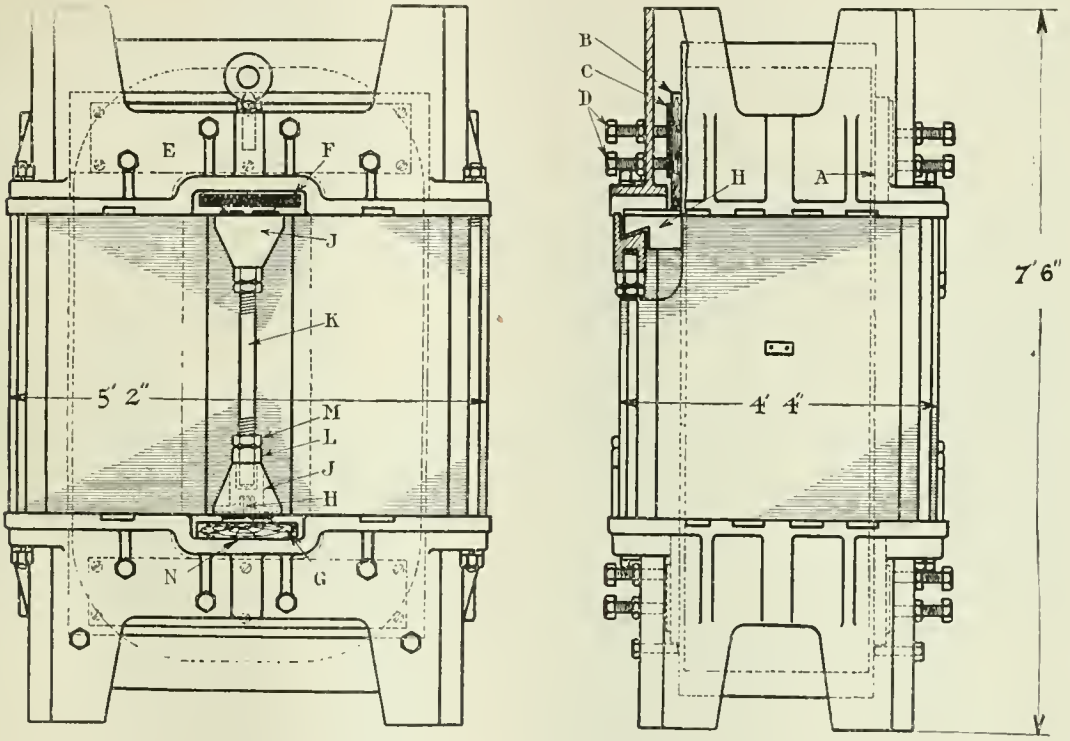



FIG. 12.

A Coil heads.
B Wood packing.
C Steel plate.
D Adjusting bolts.
E End frame.
F Wood packing.
G Wood packing base.
H Angle-iron supports.
J Supporting bracket.
K Adjusting supporting bolt.
L Adjusting nut.
M Lock-nut.

The coils are gripped at the top and bottom and hang vertically. When the transformer is dried out the insulation tends if anything to swell, by reason of the hot oil, rather than to shrink. Further, the electromagnetic interaction of the primary and secondary coils tends to produce a repulsive action between the two windings which relieves the insulation of any possible compressive stress.

*Shrinkage due to expansion of copper.*—In core-type transformers under the continued influence of hot oil and the pressure due to the expansion of the copper and the weight of the coils, the insulation of sheet pulp material compresses permanently, whereas woven

insulating material does not contract appreciably. Washers of sheet insulating material are necessary between sections on account of the considerable voltage between adjacent sections. These might be replaced by taping the individual coils in completely, but this method is generally too costly and impedes the cooling of the windings. In single-layer spiral windings the voltage between any two adjacent turns is an absolute minimum (being no more than the voltage per turn of the transformer), the amount of insulation required between turns is small and may be of linen tape or other suitable fabric, for which the shrinkage will be practically negligible.

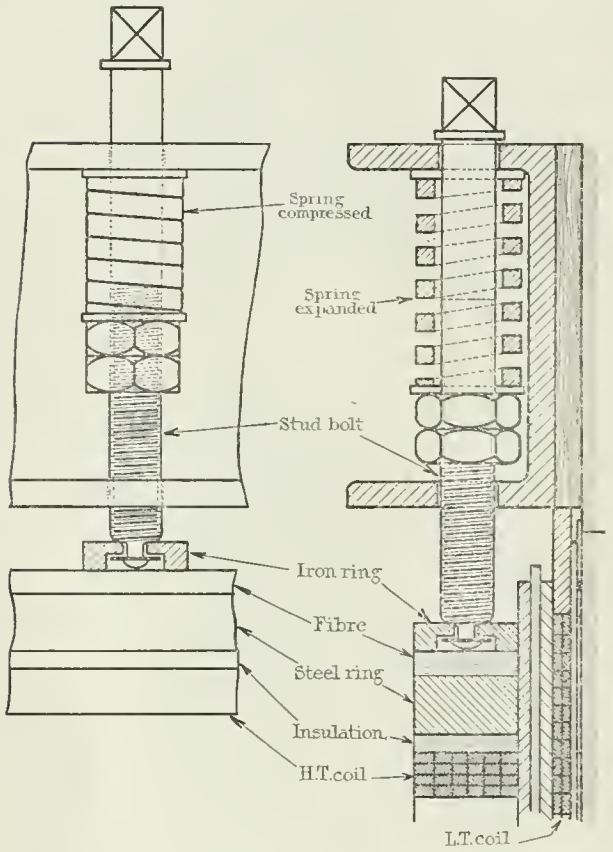



FIG. 13.—Spring coil supports for automatically taking up shrinkage of windings.

In shell-type transformers the expansion of the copper is much less than in core-type transformers, as the copper constitutes a much lower percentage of the total axial length of winding; further, there is no compression due to the weight of the coil, and consequently no periodic adjustment of the coil supports is necessary under normal service conditions.

*Bracing of windings.*—In both core and shell-type transformers all coils should be rigidly supported so that any movement due to short-circuit, vibration, or other source of disturbance is precluded.

The function of coil supports is to support the windings rigidly against any possible movement due to the causes enumerated above. Some form of coil support is essential in all transformers; and, further, in cases where shrinkage may be an important factor it may be necessary to provide means of adjustment to compensate for the shrinkage.

In core-type transformers we have to consider the two types of winding already referred to, and the function of the adjustable coil supports in each case.

In section windings, that is where the winding is subdivided into a number of coils or sections connected together, the function of adjustable coil supports is actually to take up shrinkage by adjustment from

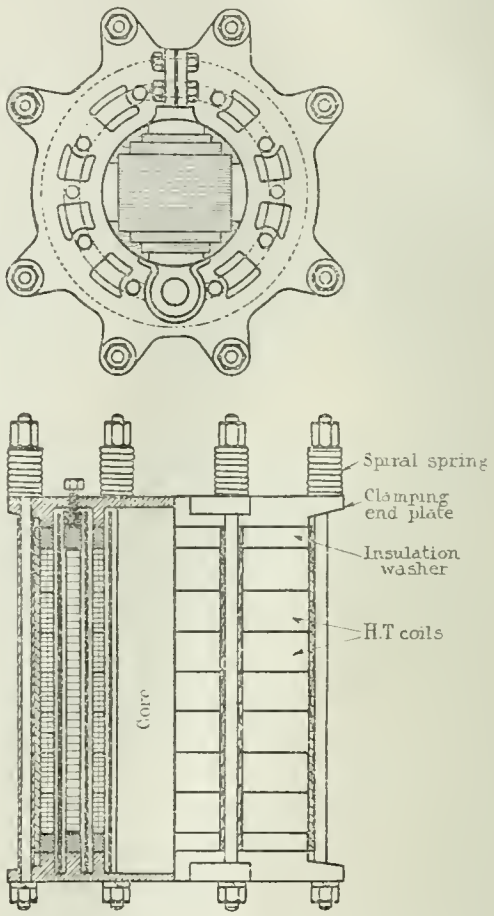



FIG. 14.—Spring coil supports for automatically taking up shrinkage of windings on core-type transformers.

time to time, whenever the transformer is opened up for inspection or shows evidence of requiring attention. In single-layer spiral windings, the thicknesses of insulation in the axial direction of the windings are usually so small relatively and the insulation between turns is to a certain extent resilient, so that the play which might be introduced by shrinkage is practically negligible. When such windings are provided with adjustable coil supports the adjustment is done once and for all after drying out the transformer in the factory. After this the adjustable coil supports are not required for adjustment.

Comparing this with shell-type transformers as usually constructed, the function of adjustable coil

supports is to brace those parts of the windings which, unless so braced, would tend to move during abnormal operating conditions, according to the rigidity or otherwise of the coil. Adjustable coil supports, when provided, are part of the ordinary constructional design of the transformer, and are not provided with a view to counteracting shrinkage, since, as pointed out above, shrinkage in shell-type transformers is of no great consideration.

*Automatic adjustment for compensating shrinkage on core-type windings.*—Various suggestions have been made for automatically compensating the shrinkage in the windings of core-type transformers. These generally take the form of spiral springs arranged so as to exert an axial thrust on the coils tending to oppose directly any axial movement due to the shrinkage of the insulation. Examples of such construction are shown in Figs. 13, 14, and 15.

A spring able to follow this amount of shrinkage and still be able to exert sufficient pressure on the windings would necessarily be very large and cumbersome, and it might even be necessary to sub-divide the spring into several springs placed at different parts of the winding axially. This leads to a complicated and inefficient construction and involves loss in winding space and higher core loss. Cases might be met in extra-high-tension transformers with large shrinkage where the springs would not be capable of following up the total amount of the shrinkage, when the function of the springs would be nullified.

Automatic adjustment appears to commend itself especially to operating engineers. While the springs provide such adjustment the above-mentioned disabilities outweigh, in the authors' opinion, the resulting advantages claimed. Vibration or movement due to

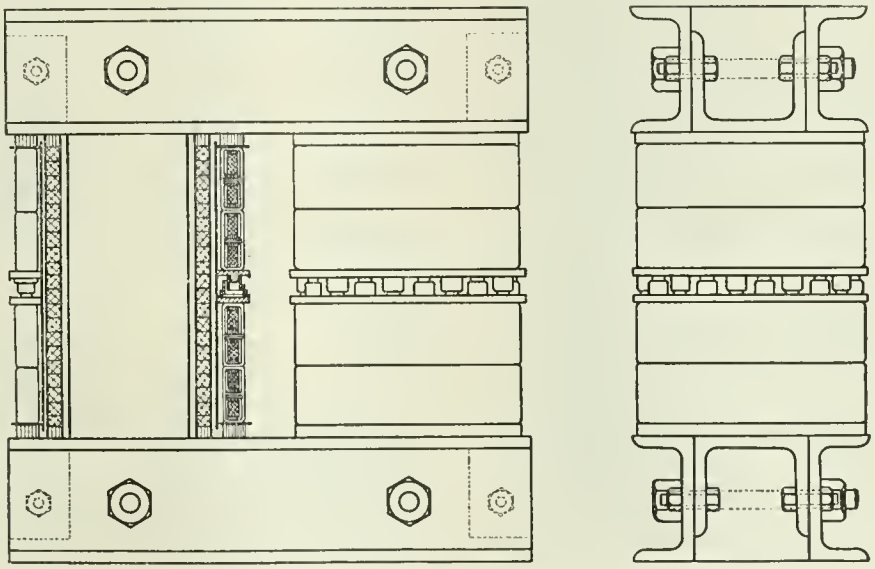


Fig. 15.—Spring coil supports for automatically taking up shrinkage of windings.

While such springs undoubtedly follow up any shrinkage that may occur, it should be remarked that, the more the springs expand, the lower the pressure they are able to resist without movement. Consequently the windings, even during normal operation, may be in a state of permanent vibration, and, under abnormal conditions of loading or short-circuit, may be subjected to considerable movement.

Any such movement is naturally undesirable as it will tend to damage the insulation, although this may only become apparent in the course of time. The spring should be so placed relatively to the windings that the weight of the latter exerts no pressure which would counteract the effect of the spring.

Attention should also be directed to another disability of the use of springs for automatic adjustment. This relates to core-type transformers with very long cores, especially for high voltages and large outputs, where the shrinkage of the windings may be as much as 1 to $1\frac{1}{2}$ inches.

shock can be overcome if some means are provided whereby the spring, after having performed its function of following up the shrinkage, is prevented from any possible recoil due to sudden shock. An arrangement due to G. Harlow * which achieves this end is shown in Fig. 16. It consists essentially of a spring which surrounds the plunger of a small dashpot and exerts pressure between the dashpot and its plunger. The plunger is supported on the top frame of the transformer and the dashpot transmits the pressure of the spring on to the windings. The dashpot is provided at the back end with a small hole serving as an oil inlet and escape. When shrinkage of the windings takes place this is followed up by the spring acting on the plunger, and any possible sudden recoil is prevented by the sluggish action of the dashpot and plunger.

The above constructions all relate to core type transformers, where the question of shrinkage of windings is of much greater significance than in the shell

* British Patent No. 9,921 of 1915.

type. In the latter type, as the shrinkage is practically negligible, automatic adjustment is unnecessary.

*Radial coil supports.*—These have been sometimes employed (see Figs. 14 and 17), but are not generally necessary except in very large core-type transformers. They act as an additional safety factor in cases where the circumferential stress in the copper under short-circuit might become excessive.

*Insulation.*—In comparing core-type and shell-type transformers from the standpoint of insulation, it may be said that, given first-class design and manufacture, there is in general very little to choose between the two types. The choice of type from this standpoint and the ultimate result depends largely on the individual manufacturing facilities. These considerations offer to a large extent the explanation of why certain manufacturers have adopted one particular type in preference to the other. However, the authors have set out below a number of general considerations regarding the two types.

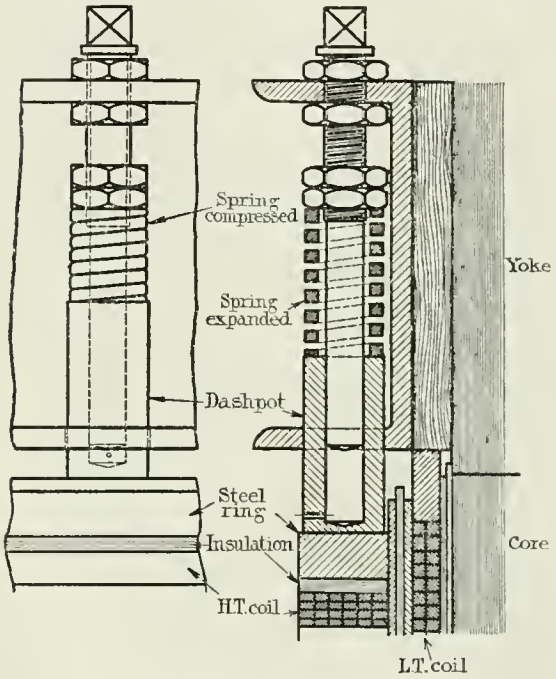



FIG. 16.—Spring coil supports fitted with dash-pot to prevent recoil of spring.

TABLE 6.

*Voltage per Turn for Core-type and Shell-type Transformers.*

| K.v.a. at 50 cycles | Shell Type | | Core Type | |
|---|---|---|---|---|
| | 1-Phase | 3-Phase | 1-Phase | 3-Phase |
| 1,000 | 35 | 20 | 15 | 10 |
| 3,000 | 60 | 35 | 35 | 25 |
| 10,000 | 100 | 60 | 60 | 50 |
| 20.000 | 140 | 80 | 85 | 70 |
| 30,000 | — | 100 | — | 85 |

*Voltage between turns.*—In the shell-type the voltage per turn is considerably higher than in the core type, as the total iron section in the former is generally much larger than in the latter.

Table 6 gives the average representative values of the voltage per turn of the two types.

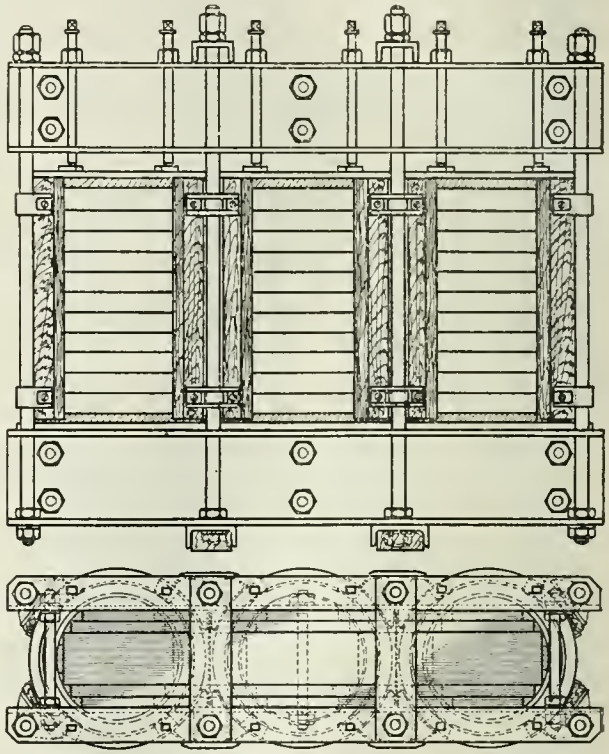


FIG. 17.—Radial coil supports for core-type transformer.

In view of the above, the insulation between turns must be heavier for shell-type designs, and this becomes more important in very large outputs.

*Reinforcement of insulation.*—The reinforcement of the insulation of the end turns is to some extent easier in shell-type designs, as the total number of turns is smaller and fewer turns have to be reinforced.

As regards general practice in this matter, for power systems with underground cables the end-turn reinforcement is less important than in transformers connected to overhead transmission lines subject to atmospheric disturbances. Underground cable systems are at present in use on the Continent and in America up to 30 kilovolts, and some systems in this country are adopting this voltage. Up to this voltage, experience shows that reinforcement to the extent of about 1 per cent of the winding per 10 kilovolts of line voltage is sufficient, i.e. for 30 kilovolts 3 per cent of the winding from each line terminal is reinforced.

The reinforced insulation should be of sufficient strength to withstand normal line voltage momentarily

between adjacent turns, in about 1 per cent of the winding. The reinforcement is usually graded in 3 or 4 steps down to the ordinary insulation on the rest of winding.

For transformers connected to overhead transmission lines up to 100 kilovolts the number of reinforced turns should generally be about 5 per cent of the total winding. The reinforcement is necessary at all ends of the winding which are connected to the line; thus in delta-connected windings both ends of each phase must be reinforced.

On switching in, the period of abnormal voltage stress lasts usually only about 1/10 second, and the voltage may rise to a maximum of up to about twice normal voltage.

The curves of Fig. 18 show the relation between breakdown voltage and time for sheet insulating materials commonly used in transformer construction.

Taking average figures from these curves shows that the insulation between the end turns of the winding need be sufficiently thick to withstand full voltage

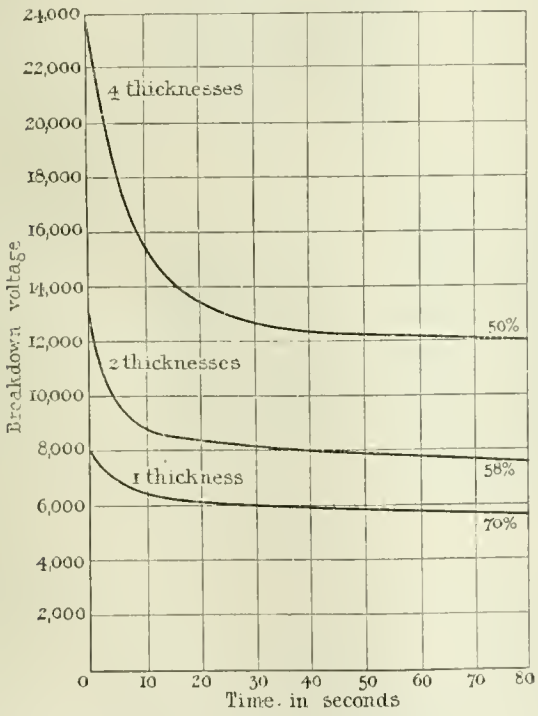



Fig. 18.—Curves showing relation of breakdown voltage and time for sheet insulating materials.

for, say, one second, which corresponds to about 60 per cent of normal voltage applied for 1 minute or more.

*Robustness.*—On the score of general robustness the shell-type transformer presents a much stronger construction which is less susceptible to damage in handling and transport. In the shell type the windings are more or less completely ironclad, and are thus naturally well anchored and braced.

Core-type windings can be braced and supported almost as rigidly, but this involves elaborate and costly details of construction in coil supports.

In the shell type the larger portion of the windings is embedded in and supported by the core laminations which serve this purpose without any special attachments.

In general any elaborate system of coil bracing, either in shell-type or core-type transformers, involves a certain amount of sacrifice in electrical performance and increase in cost. This is, if anything, more marked in the core-type transformer, since the windings in this type are not embraced by the iron as in the shell type.

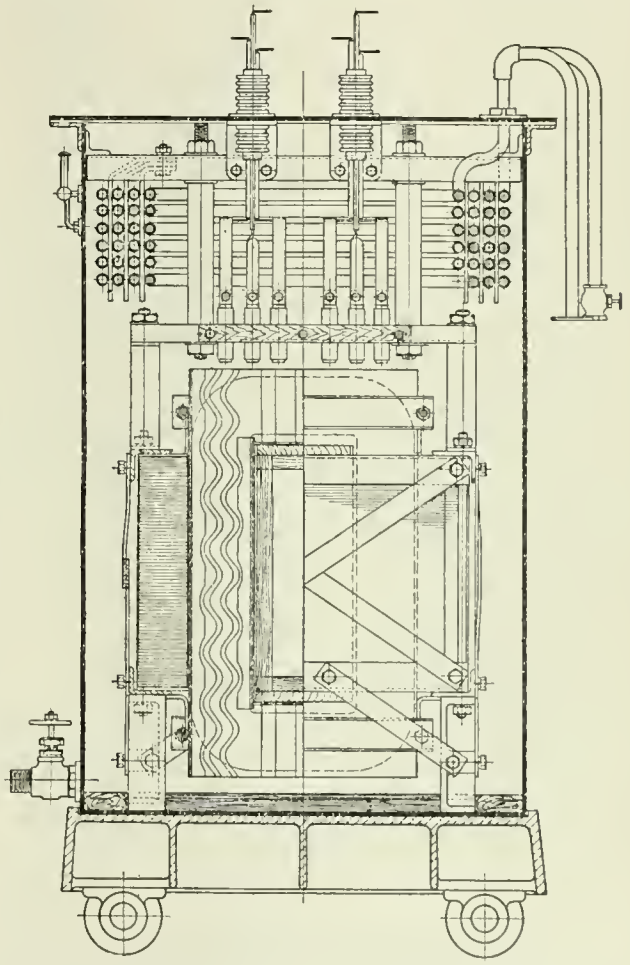


Fig. 19.—Ironclad reactance coil, water-cooled, 1,610 k.v.a. 4,200 volts, 383 amperes, 50 periods, line voltage 11,000.

Special mechanical attachments for coil bracing are not generally necessary for transformers for normal service on systems under about 20,000 k.v.a. They are, however, desirable on large transformers and on large systems, or in cases where the operating conditions are severe.

In illustration of the order of stresses encountered, the following examples will serve. On an 8,000-k.v.a. 25-period single-phase shell-type transformer having 6 per cent impedance voltage, the maximum total stress over the whole of the surface of each end coil is approximately 300 tons under short circuit conditions.

This amounts to about 3 tons per square inch of coil surface.

On a 5,000-k.v.a. three-phase core-type transformer the axial stress between high-tension and low-tension concentric windings may amount to 200 tons per leg under short-circuit conditions (assuming the magnetic centres of the high-tension and low-tension windings to be displaced from one another by an amount equal to about 5 per cent of the axial length of the coils). The circumferential stress in the outer concentric coils is of the order of 8 tons per square inch of copper section. The strength of the copper in the windings is usually sufficient to resist this hoop stress. If it exceeds the elastic limit of copper, radial coil supports should be fitted.

All coil supports and bracing must be designed sufficiently strong to withstand the maximum momentary stresses.

### (7) Inherent Protection against Mechanical Damage on Short-circuit.

With the growth of size of generating stations the question of protection of transformers against mechanical damage due to short-circuits has become of increasing importance.

In the earlier days of small stations and lower transmission voltages, step-up transformers were comparatively rare.

Distributing transformers were connected to the power stations through relatively long lengths of cable.

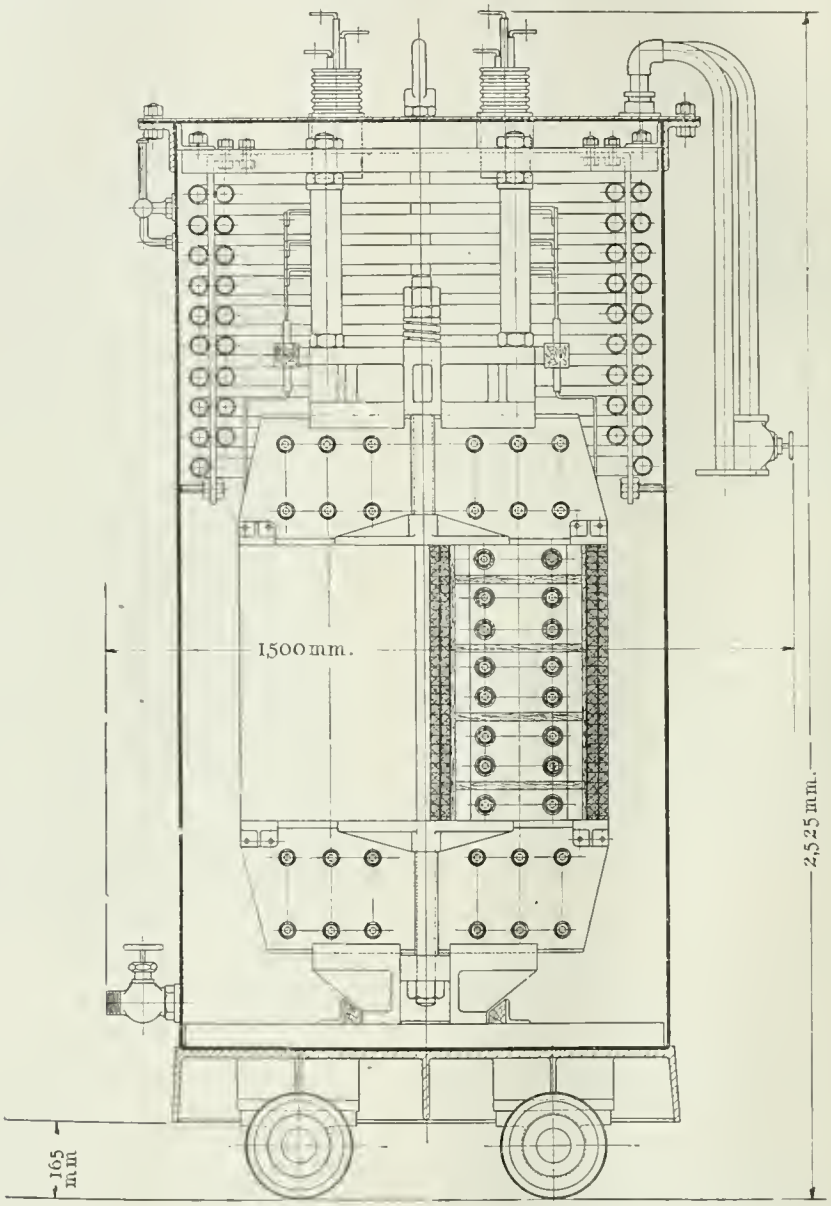



Fig. 20.—Ironclad reactance coil, 1,610 k.v.a., 4,200 volts, 383 amperes, 50 periods.

In case of short-circuit at the distributing end, the voltage drop in the cables, coupled with the low plant capacity to feed the short-circuit, sufficed to limit the short-circuit current in the transformer to such values that no excessive mechanical strains were put upon the transformer windings.

Nowadays we have to deal with supply systems up to 300,000 k.v.a. with step-up transformers situated directly on the station busbars, and distributing transformers situated often relatively near to the power station, in the case of industrial districts.

These transformers must be of sufficiently robust construction to withstand short-circuit shocks. The

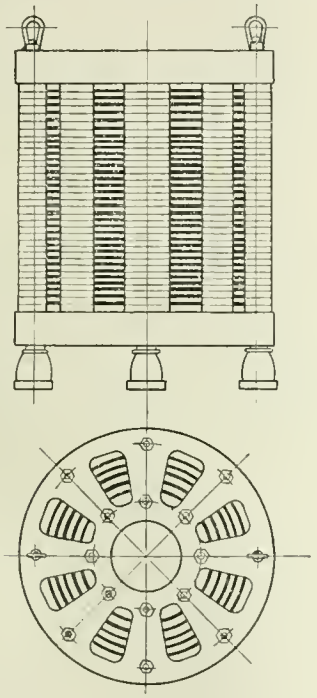


Fig. 21.—Outline of single-phase protective reactance with concrete frame.

mechanical strains may be restricted by limiting the short-circuit current. This must be done by introducing a sufficiently high impedance somewhere in the circuit—either as inherent reactance in the transformers themselves, or as external current-limiting reactances.

Actually the external reactance is more efficacious, since, with the same limitations of short-circuit current, the mechanical stresses on the windings are less than those produced when the same current limitation is obtained by internal reactance.

Questions of costs, space, and simplicity weigh against this consideration. In fact, it is quite possible, by designing the transformer with a suitable amount of inherent reactance, to limit the short-circuit stresses to such a value as can be safely dealt with by a robust mechanical construction. This is the general tendency of modern practice.

In modern large power transformers the impedance voltage is nowadays of the order of 5 to 8 per cent, which limits the short-circuit current to approximately 20 to 12·5 times normal. This limitation of current is based on the assumption of a straight-line volt-ampere short-circuit characteristic.

Actually this may not be quite the case, on account of the saturation of the iron which forms part of the leakage path and also as the leakage field tends to concentrate towards the middle of the windings under heavy currents, resulting in the current rising at a quicker rate than in proportion to the voltage.

Where it is found necessary or desirable to install external protective reactances, the following general considerations should be taken into account as regards the choice of type.

There are two types of protective reactance, the ironclad type and the air-core type.

The former consists of a choke coil with an iron core similar to a standard transformer but with a large air-gap, or a number of small air-gaps interposed in the path of the magnetic flux.

The arrangement of the magnetic circuit of a shell-type and of a core-type ironclad reactance is shown in Figs. 19 and 20 respectively.

The air-core type consists simply of a plain coil in air, the inductance of which is designed to give the required choking effect without the use of an iron core. Such coils are usually supported on concrete frames either cast in or built up, or on porcelain mountings.

Such a reactance * with a built-up concrete frame is illustrated in outline in Fig. 21.

Either type can be built to give satisfactory service. The choice depends mainly on

(1) The type of service obtaining.
(2) The location and space available.

(1) As regards the type of service, the choice reduces itself largely to a question of capital cost ; the relative prices depend on the short-circuit current required in terms of the normal current, i.e. the maximum current up to which a straight-line volt-ampere characteristic is required.

We may divide the type of service into three classes :—

(*a*) Busbar reactances.
(*b*) Generator reactances.
(*c*) Feeder reactances.

(*a*) Busbar reactances are usually arranged to limit the current transference from one section to another to about 4 to 5 times the normal current in each set of busbars, corresponding to a voltage choke in the reactance of 25 to 20 per cent of the line voltage.

(*b*) In generator reactances the current limitation is usually about 8 times the normal current, which, allowing for 7·5 per cent inherent reactance in the generator, requires an additional 5 per cent external reactance, or a total of 12·5 per cent reactance (neglecting the resistance, which is relatively small).

(*c*) Feeder reactances are generally proportioned

* The authors use the generally accepted designation "reactance" for this apparatus ; of the total impedance of such apparatus the resistance is practically negligible as compared with the reactance component.

for a smaller voltage drop of about 5 per cent, corresponding to a current limitation of 20 times normal.

In each case the volt-ampere characteristic must be approximately a staight line up to the limiting current. This is inherently attained with the air-core type but considerably influences the design of the ironclad type.

Owing to the heavy magnetic fields resulting from the large short-circuit currents, the iron sections in the ironclad type must be greater the higher the limiting current.

The result of this is that the cost of such reactances increases with the value of the current limitation for a given normal current. This consideration does not arise in the air-core type, but in point of cost the ironclad type can be designed to compare favourably with the air-core type up to limiting currents of about 8 times normal.

(2) The location of the reactances with regard to structural or other iron- and steel-work and electromagnetic instruments is of considerable importance. In this respect the ironclad type has the advantage over the air-core type in that there is no stray field.

Ironclad reactances can be installed in any location where the installation of the air-core type would give rise to disturbance of balance and possible heating trouble in adjacent iron-work. To mitigate these effects air-core reactances should be so installed that there is no iron-work nearer than a distance approximately equal to the overall diameter of the coil.

This is often an important factor where the space available is limited, as is generally the case in older stations where extensions necessitate the use of such apparatus.

If sufficient space is available, as may be provided when laying out new stations, the air-core type can be installed without possibility of trouble in this direction. It has less liability to fire risk.

The ironclad type is totally enclosed and the tank can be earthed, whereas the air-core type is mounted on insulating supports and the coils are usually exposed at full line voltage, unless completely protected by concrete or porcelain frames.

### (8) Safety Factors.

(1) *Electrical safety factors.*—The safety factor of the insulation on the windings is an indeterminate quantity in such portions of the windings as may be subjected to uncontrollable electrical strains during operation. The greater part of the winding is not subjected to such conditions, and here the safety factor of the insulation may be approximately determined from knowledge of the properties of the insulating materials and the test conditions.

In the former case, so far as can be predetermined from experience, an ample safety factor is provided for, by means of reinforcement of the insulation between turns (see page 562). For normal conditions where the factors are pre-determinable the following data give an idea of the usual safety factors arrived at.

*Insulation between turns.*—Table 6 gives representative values of the average voltage per turn for core and shell-type transformers. The figures relate to 50-period designs and vary roughly in proportion to the frequency, i.e. at 25 periods the values would be approximately halved.

The actual insulation used on conductors (apart from the specially reinforced turns) is generally of such material and thicknesses as will withstand, for mechanical and electrical reasons, the breakdown voltages between adjacent turns given in Table 7.

Table 7.

*Voltage and Safety Factor between Adjacent Turns.*

| Normal Volts per Turn | Approximate Breakdown Voltage between Turns | Operating Safety Factor | Factory Safety Factor for Over-potential Test Voltage = 2 × Normal Voltage |
|---|---|---|---|
| 5–10 | 4,500 | 900–450 | 450–225 |
| 10–25 | 7,000 | 700–280 | 350–140 |
| 25–60 | 10,000 | 400–166 | 200–83 |

The average operating safety factor (based on the normal working voltage) is thus from 166 to 900. This factor may seem high, but it is determined by the minimum practicable thickness of insulation, which is fixed chiefly by mechanical considerations; manufacturing considerations such as quality of labour, handling of windings and insulating material, humidity of the atmosphere, etc., have also to be taken into account.

Table 8.

*Voltage and Safety Factor between Coil Sections.*

| Normal Volts between Coil Sections | Approximate Breakdown Voltage between Coil Sections | Operating Safety Factor | Factory Safety Factor for Over-potential Test Voltage = 2 × Normal Voltage |
|---|---|---|---|
| 500 | 20,000 | 40 | 20 |
| 1,000 | 35,000 | 35 | 17·5 |
| 3,000 | 45,000 | 15 | 7·5 |
| 6,000 | 55,000 | 9·2 | 4·6 |
| 12,000 | 70,000 | 5·8 | 2·9 |

From the manufacturer's standpoint the safety factor must be reckoned on the test voltage to which the transformer is subjected.

Usually transformers are submitted to an overpotential test of 2 to $2\frac{1}{2}$ times normal voltage for a period of

one minute. Hence the factory safety factor (based on the test voltage) is of the order 83 to 450.

*Insulation between coil sections.*—It is possible to insulate up to almost any voltage between coil sections required in service by means of solid insulation. This method while adopted for small transformers has its limitation as the size of the transformer increases.

In coils of radial depth greater than about $\frac{3}{4}$ inch to 1 inch, investigation and experience show that it is difficult to get rid of the heat and maintain uniform temperature in the winding if the conductors and insulation form a solid congested mass. It is thus necessary to introduce ventilating ducts for the cooling medium to circulate, which themselves lead to an improved insulation between sections. This subdivision precludes liability to hot spots, minimizes the deterioration of the insulating material, and lengthens the life of the windings.

Similar considerations to the above lead to the data given in Table 8 for the safety factor between adjacent coil sections.

### Insulation between H.T. and L.T. Windings and between Windings and Frame.

Table 9 shows the average breakdown voltage for the insulation usually employed between high-tension

Table 9.

| Working Pressure | Approximate Breakdown Pressure | Operating Safety Factor | Test Pressure * | Factory Safety Factor |
|---|---|---|---|---|
| kv. | kv. | | kv. | |
| 2·2 | 40 | 18·2 | 5·4 | 7·4 |
| 6·6 | 60 | 9·1 | 14·2 | 4·25 |
| 11 | 80 | 7·25 | 23 | 3·5 |
| 22 | 110 | 5·0 | 45 | 2·45 |
| 33 | 140 | 4·25 | 47 | 2·1 |
| 55 | 200 | 3·65 | 111 | 1·8 |

and low-tension windings and between windings and frame.

Similar data for insulation between windings and the inside surface of the tank give a safety factor to earth through the oil of from 5 to 3 for the operating safety factor, and $2\frac{1}{2}$ to $1\frac{1}{2}$ for the factory safety factor, based on a disruptive strength of dry oil of 15,000 volts between needle points $\frac{1}{8}$ inch apart at 15° C.

*Terminals.*—The creeping distance over the surface of porcelain terminal insulators should be so proportioned as to allow an operating safety factor of about 3 and a factory safety factor of about $1\frac{1}{2}$; that is, the flash-over voltage of such insulators should be about three times the working voltage, or $1\frac{1}{2}$ times the test voltage of the transformers.

In concluding this section it should be observed that all the data given for the average values of safety factors are based on the products immediately on completion of manufacture. If some of the values appear to allow a large margin of safety, it must be remembered that there is a possibility of the safety factor becoming considerably reduced after some time in operation, owing to the effect of service conditions on the apparatus.

The safety factors allowed for the oil and terminal insulators are much lower than for the other insulation in the transformer, since any deterioration of the oil due to moisture, acids, etc., or of the terminal insulators, due to dirty creepage surfaces, can be readily detected and remedied at the periodic inspection.

(2) *Mechanical safety factors.*—The mechanical parts of a transformer subjected to stresses from the windings are proportioned for the usual safety factors employed in machine design, figured on the maximum possible stresses which may occur (see page 563). The same applies to parts subjected to stress during lifting, handling, and transport.

(3) *Thermal safety factors.*—In well-designed transformers the maximum temperature occurring at any point on the winding should not exceed the average temperature in the windings by more than about 5 degrees C. Where the windings are not well-ventilated or heavy sections are employed this excess may reach a value as high as 15 degrees C. or even higher.

In general the maximum temperature met with is lower than the temperature which the insulating material will stand continuously without deterioration. Table 10 gives the maximum permissible temperatures

Table 10.

*Maximum Temperatures for Insulating Materials in Transformers.*

| | B.E.S.A. Permissible Maximum Temperature (50 deg. rise on Air Temperature 40° C.) | Maximum Possible Hot-spot Temperature |
|---|---|---|
| Cotton, silk, paper, and similar materials .. | 95 | 110 |
| Asbestos, mica, and similar materials .. | 115 | 140 |
| Oil .. .. .. | 90 | 90 |

according to the B.E.S.A. Report and the possible maximum hot-spot temperatures encountered.

### (9) Interlinking of Stations.

Recent developments in the interlinking of power systems arising from questions of supply economies have given rise to conditions demanding special consideration.

* B.E.S.A. standard test voltage = 1,000 volts + 2 × normal voltage (see Report No. 72 of 1917, par. 82).

The service conditions differ from those of ordinary substation step-down transformers.

(1) Both primary and secondary voltages are usually high and the interlinking transformers must be insulated accordingly.

(2) Special means of voltage adjustments are required to compensate for the voltage drop in the lines as the load may be transferred either way, transferring the voltage drop from one side to the other.

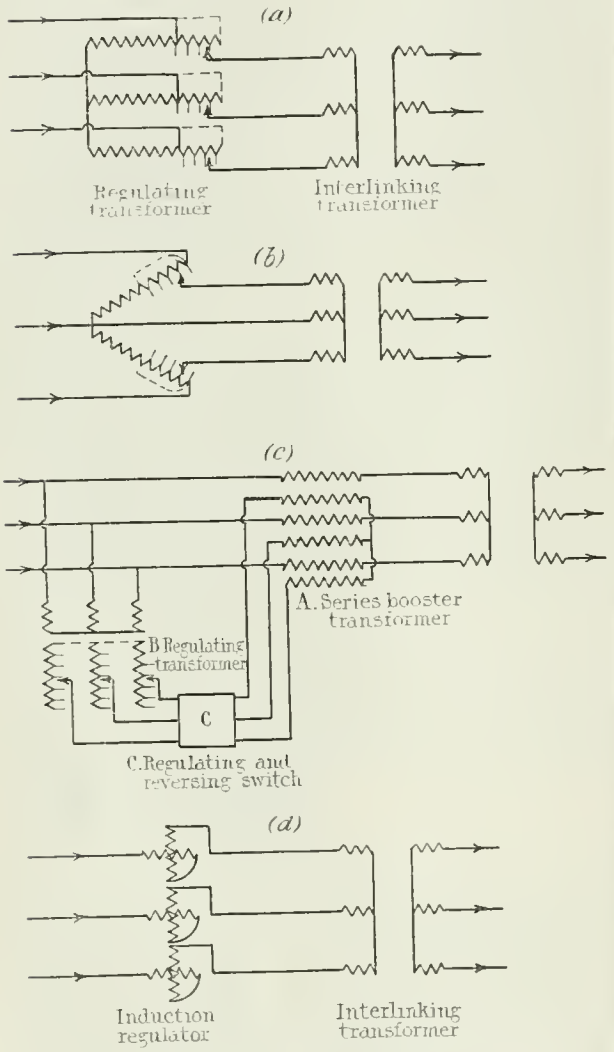



FIG. 22.—Systems of voltage regulation for interlinking transformers.

(3) The minimum size of transformer is determined by the size of the stations and the synchronizing power necessary to keep them in step.

(4) The transformers must be of specially robust construction, as they operate with a large amount of power on both primary and secondary sides.

Regarding (2), the usual means of obtaining the requisite regulation consist either of tappings on either or both sides of the transformer for, say, $2\frac{1}{2}$ and 5 per cent above and below normal voltage, or of some form of voltage regulator if a wide range or frequent adjustment is required.

Figs. 22 *a*, *b*, *c*, and *d* show the systems which may be employed.

*Connection and phase angles.*—In the case of two-phase or three-phase systems interlinked at one point the connections of the interlinking transformer, whether star-star, delta-star, etc., are of no consequence unless there are more than two stations interlinked. In this case there are two possibilities, viz. a ring connection or a star connection, as represented diagrammatically in Fig. 23 for three stations, A, B, and C respectively.

In the ring connection the interlinking transformers will simply transform from the voltage of one station to the voltage of the next, and any one station can supply power to, or draw power from, only two others, whatever the total number of stations in the ring.

The question of phase relation enters here, as the connections of the interlinking transformers must be so chosen that the phase angle is correct at all points in the ring when completed.

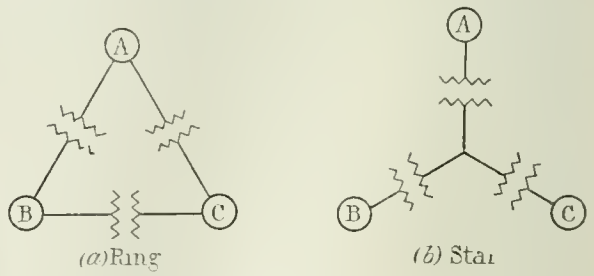



FIG. 23.—Ring and star connection of interlinking transformers.

In the star connection, which is generally preferable, each station will transform up to the same voltage on a common interlinking feeder or busbar, which may or may not form a ring. In this case any one station can, if desired, supply power to or draw power from all or any of the other stations interlinked.

If the interlinking feeder is connected in a ring it will be necessary, in order to equalize the load distribution, to install an induction regulator or adjustable reactance at one or more points. Fig. 24 illustrates an adjustable reactance built for this purpose on a split-conductor ring main.

The use of auto-transformers for interlinking systems of about equal voltages, though apparently attractive from the point of view of reduced capital cost, is not generally to be recommended.

The reasons for this are the following:—(1) The danger of abnormal pressure-rises on the lower voltage system in the event of one line on the higher voltage side going to earth. (2) The difficulty of obtaining a satisfactory earthing point should both systems require earthing. (If two systems are interlinked through double-wound transformers, the neutrals of the gene-

rators in both stations can be earthed.) (3) In an auto-transformer if one system has an earthed neutral it is impossible to operate the other system unearthed should this be desired. (4) Auto-transformers have generally a lower reactance than double-wound transformers and are thus less capable of withstanding short-circuits. Auto-transformers can, however, be specially designed for higher reactance if required, and

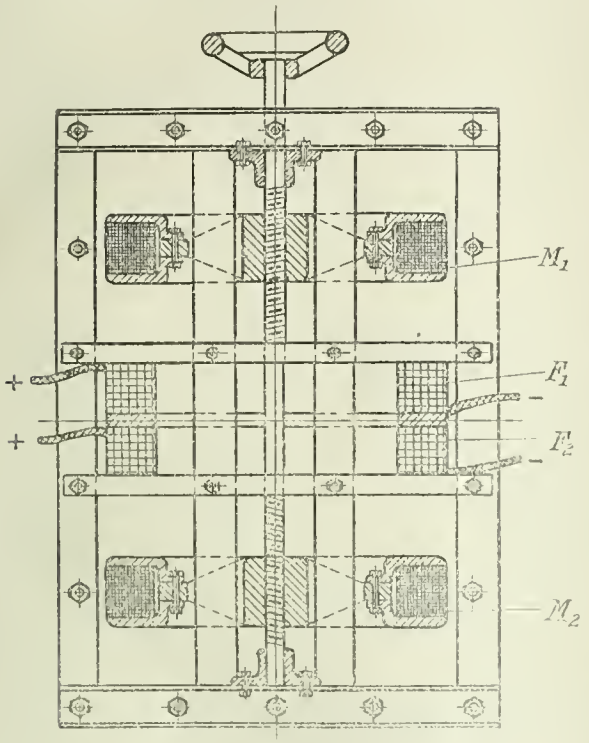



FIG. 24.—Adjustable feeder reactance.

providing the requirements of (2) and (3) are met, auto-transformers might be used for systems where the voltages of the two systems do not differ by more than 20 per cent.

### (10) TRANSFORMERS FOR ROTARY CONVERTERS.

Transformers for use with rotary converters are worthy of special mention in that they in many cases require special electrical characteristics which are not met with in standard power transformers. Where the voltage on the direct-current side of the converter is obtained by means of static or synchronizing boosters, the main transformers are of identical design and construction with standard power transformers. When the d.c. voltage regulation is obtained by means of field regulation, the transformer must be provided with sufficient internal reactance to meet the peculiar requirements.

The transformer reactance voltage required may range from 5 to 30 per cent of the full voltage according to the design of the rotary converter and the range of voltage variation desired.

This high internal reactance can be obtained either by a finer or coarser sub-division of the primary and secondary coils, or by means of magnetic shunts placed in the path of the leakage field between the primary and secondary windings of the transformer.

With shell-type transformers the coil grouping can be easily varied, and internal reactance voltages of from 8 to 10 per cent for a 500-k.v.a., up to 12 to 15 per cent for a 1,000-k.v.a. transformer, can be obtained.

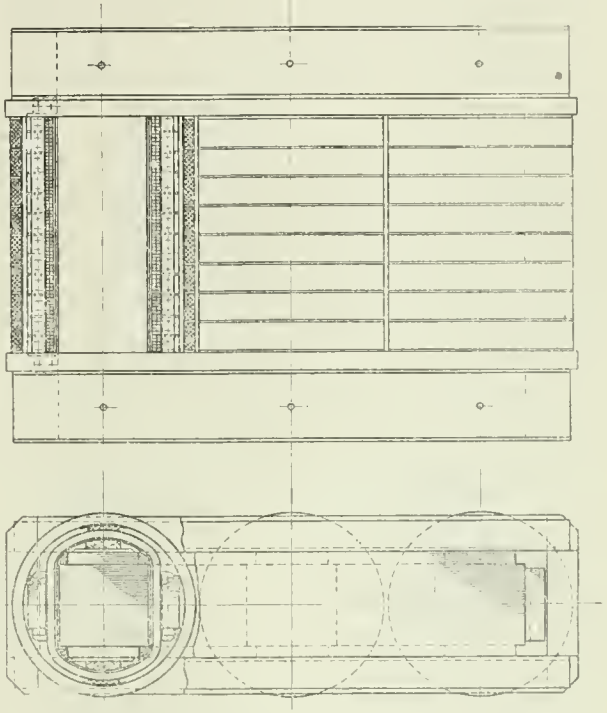


FIG. 25.—High-reactance transformer for rotary converter.

Above these values magnetic shunts generally have to be resorted to in order to attain the extra reactance required.

With core-type transformers the value of the reactance required is readily obtainable up to any required value by means of the coil grouping and suitable spacing of the primary and secondary windings. This method on account of its comparative ease of design was practically universally used up to within the last few years by most makers and is often employed at the present time. It has, however, many disadvantages, namely, expense of manufacture, high eddy-current losses in the copper and core, and difficulties in insulating the sandwich windings.

This method was superseded by magnetic shunts consisting of a sheet or sheets of iron arranged concentrically between high-tension and low-tension windings. With this arrangement, while the cost of construction was diminished and the number of insulating barriers reduced, the losses remained much of the same order. There was also another difficulty which presented itself with the use of shunts arranged in this way. The commutation of the rotary converter was found to be affected in many cases, which was found to be due to

the presence of third and ninth harmonics in the secondary voltage and consequently in the converter armature. This trouble was finally traced to the magnetic saturation of the magnetic shunts introduced into the transformer.

To avoid this it became essential that the shunts should not be saturated; in other words the characteristic of the reactance volts with load should be a straight line up to the maximum load required. These new requirements led to a new type of magnetic shunt of multiple-gap construction which was designed and patented * by the authors.

A large number of transformers built with this type of magnetic shunt are in commission and building, ranging in size from 165 to 2,200 k.v.a. for 150 to 2,000-kw. rotary converters.

Transformers of this type give a high degree of utilization of active material compared with the older types, and they are easily designed to have a straight-line volt-ampere characteristic. They also present a robust construction and have reduced losses and improved efficiency, with a resulting saving in annual charges.

A transformer of this type compared with that of the old type, either with sandwich winding or saturated magnetic shunts, would have a copper or load loss of

Fig. 26.—Packet of iron for magnetic shunt for high-reactance transformer.

only about two-thirds of that of the older types, and a corresponding improvement in efficiency. This type of construction is illustrated in Fig. 25, and also in Fig. 26, which shows an element of the magnetic shunt for one side of the core of a high-resistance transformer. While transformers with high internal reactance have not yet been built for larger outputs than 2,200 k.v.a. it is quite possible to do so up to any required size, the limiting output being that of the rotary converter.

### (11) Operation and Care of Transformer Installations.

(*a*) *Switching in and out.*—The switching in and out of transformers, while an easy operation, may present difficulties unless the transformer is correctly designed. There are two main difficulties possible during switching, viz.—

(1) Heavy current rush and
(2) Sudden high-voltage rise.

(1) The heavy rush of current, which is a magnetizing current, does not cause any severe abnormal mechanical strain on the windings, but may cause inconvenience by operating the overload relays. The correct way to switch in is slowly to close the switch, during which interval the distance between the contacts becomes smaller until the voltage causes the current to jump across the gap. This jump will take place at or near the point of maximum voltage, which is the point of the wave desired for minimum current rush.

(2) Voltage rises are frequently experienced when switching a transformer in and out, and the rise is higher the lower the flux density in the transformer core. If the switch is closed at the maximum point of the voltage wave no rise of voltage will be experienced unless the core has residual magnetism. In modern transformers the possible voltage rise will not exceed 1·6 to 1·8 times normal voltage unless the flux density is low, when it may reach a value up to 3 to 5 times normal voltage under adverse switching conditions. This latter condition is rarely met with except in high-

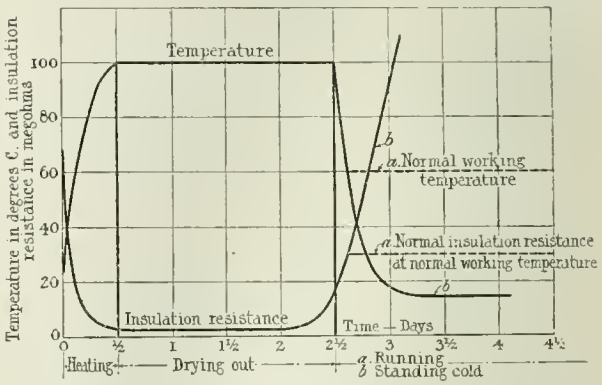



Fig. 27.—Curves showing variation of insulation resistance with temperature and time, for oil-immersed transformers before, during, and after drying out.

Note.—The actual values of time and insulation resistance are only average representative figures.

frequency transformers. A similar result occurs when switching out a transformer. From the above, frequent or unnecessary switching should be avoided and transformer switches should be closed slowly.

By taking the above precautions it is quite possible to switch large and high-voltage transformers directly on to the line without danger.

(*b*) *Drying out.*—All transformers of moderate and high voltage should be dried out before being put into service. The insulation resistance should be measured during the drying-out period, and the values should follow the characteristics similar to the curve shown in Fig. 27, if the process is proceeding satisfactorily.

"Megger" readings of the insulation resistance values, while they are useful, are not safe figures on which to base an assumption that the transformer is dry. For safety, unless the actual detailed history of the transformer is known, it should be dried out whatever the measured insulation resistance.

To obviate the inconvenience of drying out on site it is desirable, as far as possible, to ship transformers in their tanks ready for service, the drying out being done before leaving the factory. The tank construction

* British Patent No. 110,070 of 1917.

must be sufficiently strong to withstand any shocks during transport and handling the transformer complete in oil on site.

(*c*) *Inspection.*—Periodic inspection of all transformers of other than small capacity should be regularly made. This should take place every 6 to 12 months according to size, voltage, and severity of service. Any auxiliaries such as coolers, pumps, etc., should also be subjected to this inspection. The principal points to be watched for in such inspection are shrinkage of windings, slackening of core-clamping bolts, moisture and sludge in oil, deterioration of insulation due to heating, freedom of oil or air ducts from dirt or dust.

In medium and large transformers the oil should be filtered about every 12 months, and in large installations a filter press for this purpose is an essential part of the equipment.

(12) Influence of War Conditions.

As against the impetus which the exigencies of the war have given to many classes of engineering manufacture, the effect of war conditions has been to retard the development of, and to increase the difficulties in, the manufacture of electrical machinery.

One of the principal factors in this connection is the quality of the materials essential to electrical machinery, in which there has been generally considerable depreciation. This factor is felt more in transformer work than in any other class of electrical machinery, as high efficiencies are expected and high voltages are concerned. The efficiency is dependent chiefly on the quality of sheet iron, and the electrical safety factor of the apparatus depends largely on the quality of the insulating materials available.

The figure of loss of transformer sheet iron obtainable in England has increased appreciably during the last three years, resulting in higher core losses and decreased efficiency, or increase in active material and cost if the efficiencies are maintained.

The magnetic quality has not appreciably changed, but this factor is of relatively little importance in transformer design, as the magnetizing currents amount usually to only a few per cent of the full-load current.

Copper is the most stable of all materials used in electrical manufacture. Apart from increase in hardness which has at times been evident, introducing more difficulty in winding, copper has remained up to pre-war standard.

Insulating materials have almost all deteriorated since the beginning of the war. The effects of this have had to be met either by increasing the thicknesses of insulation, with a corresponding increase in cost and lowering of efficiency, or by maintaining the cost and efficiency and lowering the safety factor and quality of the finished apparatus.

Of these two courses the former is decidedly preferable and has been generally followed. The question resolves itself into the well-known general proposition in all electrical design, viz. that the choice must be made between cheap apparatus of second-rate quality, or thoroughly reliable apparatus at a higher price.

It must also be borne in mind, especially under present conditions, that the attraction of high efficiency may be obtained at a sacrifice of reliability and durability.

The restriction of the import market in materials required for electrical work, necessitating the meeting of the demand almost exclusively by home production under very difficult conditions, has had an unavoidable effect on the quality of material. In this matter labour questions such as dilution, reduction in supply of skilled workers, and substitution of women labour, have also played an important part.

The authors wish to record their thanks for the facilities afforded in the preparation of this paper by the British Westinghouse Electric and Manufacturing Co.; also to the Newcastle Electric Supply Co., Messrs. Brown, Boveri & Co., the Oerlikon Co., and the American Westinghouse Co., for information which has been of considerable assistance in compiling data in the paper.

North-Western Centre, at Manchester, 11 March, 1919.

**Mr. H. G. Furlong:** There are many points in the paper on which I disagree with the authors. I do not entirely agree that opportunities have not been afforded to transformer manufacturers for making large transformers in this country. There have been and still are opportunities for manufacturers to make large transformers, but some manufacturers frighten the customer by explaining the imaginary difficulties of designing and making large units, possibly because their shop equipment or design of transformers lends itself better to the production of small units. There is no reason whatever why three-phase transformers should not be made in single units of the same capacity as turbo-generators, as the transformer would occupy less space, the total weight would be considerably less, and the capital and running costs would also be lower than a group of small three-phase or single-phase units. The transformer should be more reliable and less likely to fail than the turbo-generator, failures due to the transformer constituting not more than 1 per cent of the total failures. The authors state that in very large stations three-phase units of 30,000 to 40,000 k.v.a. would be practicable, but that the question of handling will often be the determining consideration. If the crane is capable of handling the heaviest part of the turbo-generator, and assuming, as is general practice, that the transformers are in the same room as the turbo-generator, it will be capable of handling the transformers complete, and therefore there would be no necessity from this cause of using a group of smaller transformers either three-phase or single-phase. With regard to the method of cooling, there is very little to add to the authors' remarks. Three-phase transformers above 5,000 k.v.a., 50 periods, should certainly be forced-cooled, although it is possible to make self-cooled transformers up to 10,000 k.v.a., but this would be very expensive. The best method of forced cooling is with forced oil circulation through

an external cooler. The disadvantage of the oil pump and motor is more than counterbalanced by the advantages mentioned by the authors. Thermostats can be fitted to the transformers so that in the event of the temperature becoming excessive due to any cause, the attendant in the main station can be warned or, alternatively, the thermostat can be arranged so that it will operate the switch relay and thus cut the transformer out of circuit. The relative merits of single-phase and three-phase transformers, also core and shell type, have been dealt with by the authors at some length, but they make a statement that there is very little to choose between the two types and then go on to explain the great advantages of the shell type over the core type. This seems very inconsistent. The three-phase transformer has higher efficiencies, lower capital cost, and requires less floor space than a group of three single-phase transformers. With regard to spares and continuity of supply, I do not consider that the single-phase transformer has any real advantage over the three-phase transformer. If a three-phase transformer is installed of equal capacity to the turbo-generator, the engineer is only putting the same amount of faith in the transformer as he already does in the turbo-generator. The authors' remarks regarding single-phase and small three-phase units apply more to turbo-generators where the risk of breakdown is very much greater. With regard to substations, it is usual for engineers to standardize the sizes of their transformers, and if a spare transformer is kept at their stores it could very soon be installed in the event of a breakdown on any part of the system. Also spare coils could be kept to replace those burnt out, and provided the transformer is of the core type and built on modern practice this should not occupy more than 12 to 24 hours. If the transformer is of the shell type it is invariably necessary to return the transformer to the manufacturer for repair. I agree with the authors that the question of core and shell-type transformers is usually prejudiced by the particular views and experience of individual manufacturers and power-supply engineers, but as a designer and manufacturer of both types I think I can speak without prejudice. Both types can be constructed with either circular or rectangular coils. The core type and the circular shell type have great advantages over the shell type as illustrated in Fig. 12, as the coils are in direct contact with the oil and hence are more easily cooled than the rectangular shell type. The authors claim that the rectangular shell type has this advantage over the core type, but if one refers to Fig. 19 it will be noticed that there are waved distance strips between the coils forming channels for the oil to pass through. After the transformer has been working for some time sludge will collect in these channels and thus block up the oil path and the heat from the coils will have to be transmitted through the iron instead of being carried away by the oil. Owing to the shape of these channels it is practically impossible to remove the sludge without dismantling the transformer. In the core-type transformer it is a simple matter to arrange straight oil ducts of ample size so that they may easily be cleaned without dismantling. The problem of bracing core-type transformers is not as difficult as the authors state; in fact they can be more efficiently braced than the rectangular shell type. The coils on the core type are more liable to damage when handled out of their tanks, but as nearly all transformers are dispatched in their tanks this point is not worth considering from the purchaser's point of view. The authors also contend that the shrinkage of insulation in the shell type is less than in the core type. I can hardly believe that they put this suggestion forward seriously; their argument is certainly not convincing. They admit that the amount of insulation is large, but assume that shrinkage is entirely due to pressure; this is not so, but even if it were, the electromagnetic interaction of the primary and secondary coils produces pressure on the insulation due to the repulsive action between the two windings, and this is the principal cause of shrinkage, although the authors contend that it relieves the compression stress. These stresses in many cases are greater than the stresses due to the weight of copper in the core-type transformer, and hence the shrinkage and the need for adjustable clamps are as great in the shell type as in the core type. The amount of shrinkage is least in single-layer spiral windings; but even in this type of winding, insulation end blocks are liable to shrink after being in service and it is advisable to provide some simple arrangement for tightening the coils. The authors point out that adjustable coil supports in this type of winding and in shell-type transformers are not provided with a view to counteracting shrinkage, since shrinkage in shell-type transformers is of no great consideration. I should like to point out, however, that the slightest amount of shrinkage is of great importance and should in some way be taken care of, otherwise the coils will be likely to move when switching on or when heavy loads are thrown on to the transformers; this movement will increase gradually and eventually damage the insulation and cause breakdown, irrespective of type. The authors show four methods of automatically taking up shrinkage of coils. Figs. 13, 14, and 16 are practically identical and, although they are all capable of automatically taking up shrinkage, they all have the objection that in the event of any tendency for the coils to move outwards the spring is liable to close and allow the coil to move. The arrangement shown in Fig. 16 is an improvement on that shown in Fig. 13, but does not overcome the objection mentioned; it certainly does not allow the coil to rise so rapidly, but it will allow the coil to move outwards and afterwards drop back into position again. The arrangement shown in Fig. 15 is the only one I know which gives the desired result. The shrinkage is automatically taken up by springs placed in the centre of the leg, i.e. the neutral magnetic positions; the end coils are thus pressed against fixed abutments so that the coils are prevented from moving due to any outward tendency. There is no tendency for the coils to move inwards and compress the springs, and therefore the authors' chief objection to this method is removed. In referring to the fact that the more the springs expand the lower the pressure they are able to resist without movement, the authors seem to

have overlooked the fact that this remark really only applies to the arrangements shown in Fig. 13, 14 and 16, as the springs in Fig. 15 have only to be strong enough to support the weight of the top half of the coils when fully extended. A separate device is also arranged on transformers with very long cores for tightening the springs after they have expanded, so that it is unnecessary to sub-divide the spring into several springs placed at different parts of the winding axially. These remarks regarding automatically taking up shrinkage apply equally well to shell-type and core-type transformers. Insulation has been one of the greatest problems to transformer manufacturers during the war, but fortunately it has now been practically overcome by the larger firms installing their own plant and manufacturing insulation suitable to meet their requirements; therefore, so far as insulation goes, there is very little to choose between core and shell-type transformers—both have advantages and disadvantages which may influence their use in particular cases. In referring to the robustness of the two types, the authors state that to brace the windings of a core-type transformer involves elaborate and costly details of construction in coil supports; I have not found this to be the case any more than properly bracing the shell-type transformer. Any elaborate system of coil-bracing either in shell or core transformers naturally involves a certain amount of sacrifice in electrical performance and increase in cost, but this remark applies equally to a well-insulated transformer compared with a poorly insulated transformer. The figures which are given on pages 563 and 564 regarding stresses are interesting, but if spring coil-supports as illustrated in Fig. 15 were fitted to the 5,000-k.v.a. three-phase core-type transformer the magnetic centres of the high-tension and low-tension windings would not be displaced by 5 per cent of the axial length of the coils and therefore the stresses would be reduced very considerably. If spring coil-supports as illustrated in Figs. 13, 14 or 16, were used it might be possible to produce this amount of difference between the coils; if so, this seems to be quite a good argument in favour of the type shown in Fig. 15. It has been suggested that springs as shown in Figs. 13, 14 and 16, can be placed at both ends of the winding; but if this is done, the possibility of damage due to movement of the coils is greatly increased since this allows both halves of the winding to move outwards. The whole question of springs can be summed up as follows. The springs should not under any conditions have to take the electromagnetic strains but should only take up shrinkage and hold the coils against fixed abutments. The electromagnetic strains should be taken by these fixed abutments; consequently the only satisfactory way of using springs is to divide the coils at the magnetic centre as shown in Fig. 15 and place the springs there. On the question of reactances I have nothing to add; the authors' views regarding types and uses coincide with my own. The safety factors given in Tables 5, 7, 8 and 9, are quite reasonable, some are perhaps on the low side, as these will be reduced considerably after being in operation for some time, especially if the transformer is subjected to heavy overloads and high temperatures. If all engineers would work to the British Standard Rules and not subject their transformers to overloads under any condition, these safety factors could be reduced and consequently the prices would also be reduced and the designs improved. I am surprised that the authors have omitted to mention furnace transformers in their paper, especially as electric furnaces are now being used to a much larger extent in this country. The design of the furnace transformer is usually special, as it has to be made so as to withstand frequent short-circuits. I have been responsible for the design and manufacture of numerous furnace transformers ranging from 150 to 10,000 k.v.a. Some of the transformers have been shell type and others core type, and both types have proved equally satisfactory. The 10,000-k.v.a. transformers were three-phase oil-immersed forced-cooled units, core type, 6,600 volts 50 periods on the primary, and 115 volts 50,000 amperes on the secondary, with an internal reactance of 12½ per cent. The transformers complete with tank and oil weigh approximately 26 tons, the dimensions being 9 ft. × 8 ft. × 9 ft. over the terminals. Personally I think that there is a great future for the electric furnace and consequently for furnace transformers.

**Mr. G. F. Sills:** On page 547, and also on page 549, the authors draw attention to the importance of drying out transformers at the works and in oil. It is not usually realized by the purchaser that it is quite impossible to dry out on site as thoroughly as one can dry out in vacuum in the works. I am not quite sure what the authors mean by paragraph (*a*) on page 549 regarding the size of the transformers. I have seen a 5,000-k.v.a. transformer of the three-phase type, 50 periods, lying on its side on a truck. On page 552 reference is made to the amount of space which should be available round transformers. This point is often overlooked. I have seen three instances lately of transformers placed in a pit. In one station there were two transformers with just enough space to allow a man to go down between them. The engineer in charge said he did not like going down there. There has been a certain amount of dissatisfaction with water-cooled coils inside the transformer, but I think it has often been because the right material has not been used for the internal cooling pipes. If copper or brass is used—which is the common practice—a considerable number of brazed joints have to be made and are under the oil. Any minute pinholes in the brazing will cause trouble. The proper metal to use is a lead alloy which can be bought in long lengths and save the necessity of making any joints under the tank cover. A number of turns are put in parallel. Lead alloy can be obtained to stand up to a test of 250 lb. pressure, which is ample for anything required and there is no possibility of the water getting into the oil. This test will ensure that the thickness of the pipe will last the life of the transformer. Moreover, it is possible to use comparatively impure water, as is often necessary in these stations, especially when they are in out-of-the-way places and are unable to depend upon a town's supply for water. With stations in out-of-the-way places it seems to me it will be much better to put in smaller

self-cooled units than air-blast cooled transformers which necessitate the use of fans and somebody to attend to them. The smaller units of the self-cooled type may cost more in the first place, but it is much the best thing to do. Coming to the question of three-phase and single-phase transformers, it is rather interesting to note that about eight years ago in the States and in Canada it was standard practice to put in large single-phase transformers, but in Europe the three-phase transformer was in favour. It seems now to be the other way round. Europe wants single-phase and the States three-phase. In my view three-phase plant should go in the big step-up transformer stations where there is a larger number of transformers, and the output will generally warrant a complete three-phase unit kept as a spare. In the smaller substations single-phase transformers should be used, with one as a spare. On page 554 some dimensions are given. I saw two 14,000-k.v.a. 100,000-volt water-cooled (internal coils) three-phase transformers in Montreal. The dimensions, as far as I remember, were 23 ft. long, 18 ft. to the top of the terminals, and 9 ft. wide. No mention has been made of the cost of the station. In a large station with modern three-phase transformers it should be possible to save a considerable amount in the building, and if the building is going to cost so much more in the future this means a still greater saving. In the paper various efficiencies have been given. I should like to know whether these are with the transformer at its normal working temperature or cold. The purchaser wants to know what the transformer will do at the normal working temperature, i.e. not cold. On page 557 various firms are mentioned as making transformers and I see the Westinghouse are put down for shell type, single-phase. Several slides were shown of this make and of the shell type, three-phase. With reference to the method of taking up shrinkage, I think the disadvantage of the design shown in Fig. 15 with the springs in the middle is that iron is introduced between high-tension coils. On the question of the types of transformers it seems to me the authors have made out a very good case for the shell type, but I think that a still better case could be made out for this type with butt joints because of the ease of assembling and repairing. It is also possible to brace in a much more satisfactory manner than with interleaved laminations. In practically all core-type transformers bracing is conspicuous by its absence. Not long ago I saw an illustration of a recent 4,000-k.v.a. transformer and there was practically no bracing at all worth mentioning. The previous speaker made a remark about the coils in the core type being in direct contact with the oil and hence more easily cooled. I think that is rather misleading. It certainly appears that the oil is all round the coil. So it is, on the outside, but in most cases the heat has to be transmitted through two or three layers to the oil. With a well-designed shell-type transformer and with a single-layer coil, oil is brought into contact on at least one side of the whole coil—what we may call the pancake type of coil—and on the low-tension coils where the section is heavier it can be arranged to get oil on both sides of the single-layer coil. If the transformer is properly designed and the thickness of the coil made not more than, say, 12 to 15 mm. it will more easily transfer its heat to the oil and avoid hot spots. A core-type transformer with any type of single-layer coil is very weak mechanically. On page 571 the authors refer to moisture and sludge in oil. It seems to me that if we are going to adopt these huge sizes of transformers everything possible should be done to make them reliable, and if by using an expansion vessel it is possible to keep the oil from sludging and in the best possible condition, also to keep the moisture out from the main tank, it is the right construction to use. This simple and practicable device has been used on many hundreds of transformers made in this country, and as its use is based on simple fundamental physical facts the practical and beneficial use cannot be denied. From inquiries made, transformers fitted with this device are particularly free from breakdown. This feature becomes of vital importance on large and extra-high-voltage transformers. I have just learnt that the largest makers of transformers in the world who are situated in the U.S.A. are now providing an oil conservator. The best quality only of transformer oil procurable should always be used on a transformer. The making of the oil-tight cover joint at the top of the tank is quite simple and I can definitely state that it is easier to make this joint than the welded joints of the tank. I agree with the authors' remarks that buyers should look into details of construction before purchase. On the question of the high-voltage transformers it is interesting to note that a 250-k.v.a. 500,000-volt transformer was made in this country seven years ago and is now in operation for testing purposes. It has actually been up to 475,000 volts. The paper refers to the question of switching in. There is no doubt that buffer resistance should be embodied in the oil switch and placed so that the circuit is made and broken through a resistance. This arrangement cuts down the current to quite a safe figure and should be used with all makes of transformers.

**Mr. A. J. Cridge:** I must disagree with Mr. Furlong when he says that nearly all transformers are shipped in oil. My experience is that something less than 10 per cent of the transformers manufactured are so shipped; if that proportion could be considerably increased it would be a very desirable thing to accomplish. Objections have lately been raised by the Railway Executive Committee to the transport of transformers in their tanks, whether with or without oil, except at owners' risk. It is desirable that steps should be taken by the manufacturers to bring about a reconsideration of that view—possibly under the condition that the tanks should be of approved strength. Some reference has been made to the question of headroom, and in these days of expensive buildings it is of course necessary that this should be as small as possible. It has been suggested that the side of the tank should be removable, so that the transformer could be taken out by lifting it a few inches from the floor. Personally I think there would be serious difficulties in the direction of making an oil-tight joint, but I should like the authors to consider the matter and deal with it in their reply. The authors state that

a three-phase tank must stand upright, while single-phase tanks may be transported on their sides. Why? The long, narrow, three-phase tank should lie on a truck as well as the wider and shorter single-phase tank of the same height; and, using the same proportion as those used by the authors for single-phase, the limiting size of three-phase transformers transportable by rail might be increased to 8,000 k.v.a. or even more. I should like to have some explanation of the curious rise in the weight per kilovolt-ampere for sizes above 3,500 k.v.a. at 55,000 volts, shown in the curve on page 550. I am very glad the authors have directed attention to the necessity of providing ample room for transformers in substations. It is common knowledge that inadequacy in this respect has been a frequent source of trouble in the past, and I hope the designers and builders of substations will give the question serious consideration. The authors have mentioned the superiority of forced cooling over water cooling for transformers of large size, on account of the better circulation of oil through the interior. In my view, however, they have not made enough of the point. Particulars should be given of the increased size of transformers which can be put in the same tank when forced cooling is used. They express the hope that the B.E.S.A. specification will be adopted. I hope so too. The way to bring that about is for every customer to adopt it and get rid of his own individual specification. If customers do that, manufacturers will be obliged to follow. The load curves on page 558 are very interesting. They are scaled in kilowatts. In Fig. 10 the average load is something like 150 kw. and the power factor is approximately 0·62. This means that the transformers and cables have to be large enough for over 240 k.v.a., which shows the undesirability of what is generally described as "idle" current. Such current is not idle, but actively harmful. The point I want to bring out is that it is high time somebody got to work and designed a meter to record kilovolt-ampere-hours instead of kilowatt-hours, so that such loads may be made to pay their proper share of the costs. Much has been said, in the paper and in the discussion, about bracing. In rectangular coils in shell-type transformers serious distortion may take place owing to expansion of the copper when heated by the passage of current, and some freedom should be allowed for this expansion to take place without damage. In my opinion bracing may sometimes be overdone. With reference to the authors' recommendation on page 570 to close the switch slowly, I consider it very improbable that there is any spark at the moment of making the circuit, especially under oil. Can the authors support their view by any experimental evidence? There is no reference to the relative merits of butt joints and interleaved joints in core-type transformers. Continental practice has been to use butt joints almost exclusively, and the large German transformer referred to by Mr. Thompson when exhibiting the slides as having recently been rewound, had butt joints at the bottom end, as well as the top end, of each leg. Another point to which no reference is made is that constant temperature is not reached until much later than was at one time thought to be the case. The temperature is sometimes regarded as constant when it rises by 1 degree C. per hour, but this may go on for five or six hours. Two speakers have raised the question of sludge in the oil. The only preventive remedy for sludge is to use the best oil. The oil expansion chamber is no use. The transformer must not be run too hot, and the best oil must be used. Nothing else will do.

Mr. S. J. Watson: This paper comes at an exceedingly opportune time because, in connection with national electricity supply in the immediate future, we shall use generating units of much larger size than has been the case in the past. The transmission pressures which in this district are round about 6,000 or 11,000 volts will be raised considerably, and in all probability the main transmission pressure between power stations will be 30,000 volts. To obtain this pressure it will be necessary to insert step-up transformers between the alternator and the busbars because we cannot conveniently generate at so high a pressure as 30,000 volts on the alternator. At the present time, generating units of 20,000 kw. capacity are being installed, and, in the future, units at least double this size will be used in a busy industrial district such as this. The transformers will consequently have to be of a correspondingly large size. It is a matter for congratulation that the large transformer question has already been tackled and that makers are to-day able to put forward instruments of a suitable kind to deal with the problem. If the transformers which they turn out in these large sizes are of the excellence which we have been accustomed to find in the smaller sizes we shall be quite satisfied. Speaking generally, transformers give far less trouble than any other apparatus which we handle in connection with supply problems. There is one small point in the paper which I think has not been driven home. That is the fact that at 25 cycles transformers are 35 per cent more costly and 40 per cent heavier than they are at 50 cycles. As this district has standardized 50 cycles we are placed in a better position than those where the periodicity is appreciably lower. It may be considered a small matter, but it is nevertheless one that influences the selling price of the commodity in which we are interested and will lead to a rather quicker development than would otherwise be the case. A point of great importance is the question of using single-phase or three-phase units. I imagine it is more likely to become the practice to adopt single-phase units in these very large sizes than to adopt the three-phase type, owing to the convenience and lower cost in providing spare units for use in an emergency. Of course three single-phase units will occupy a larger space than one three-phase unit, but in the majority of our generating stations I do not think there will be much difficulty in this direction. One of the previous speakers dealt with the problem of lifting-tackle for these large units. We shall in any case have to provide lifting-tackle of at least 100 tons' capacity in connection with the main plant, and if it will deal with the main plant it will be of sufficient capacity to lift any transformer which may be required in connection with it. I do not think it is really a question of the lifting-tackle inside the power station; it seems to me it is more

a question of transport. Certain difficulties may be experienced, but with some attention they can be overcome. It adds considerable value to the paper that a comparison of prices is given. In the past it has too often been a fault that different types of apparatus have been discussed without information being given as to the values. The figures of cost set out in the paper make it much more valuable than it would otherwise have been. I would ask the authors whether the prices given for the large transformers include pumps, oil tanks, and circulation arrangements. In connection with large units, that must add appreciably to the cost and it is not clear from the paper whether it is included or not. The authors might have given a little more information regarding regulating transformers. There is no doubt that these will have to be provided with all lengthy interconnecting mains, and I should be glad if the authors would state the approximate cost and the losses which occur in dealing with the two extreme ranges. Something requires to be done in regard to the standardization of sizes of transformers. I do not know whether the B.E.A.M.A. has considered this matter which is of some importance. A few years ago I erected a substation with an entrance to take a certain size of transformer and allowed, I thought, ample margin for emergencies. The transformer was purchased, however, from another maker, the entrance was found to be far too small, and we had to enlarge the door appreciably. Such things ought not to happen and it would be an excellent idea to standardize dimensions. In view of the high pressures that will be used in connection with these large units I should be glad to know what form of earth shield is being employed.

**Mr. F. H. Williams:** I quite agree as to the great advantage of transporting in oil and I gather that the authors do not consider it feasible for foreign shipment. That is my own opinion There appears to be a misunderstanding with regard to the crocodile trucks which are said to be available in this country up to 50 tons' loading weight. I believe that applies only to an evenly distributed load and that the actual loading for a central load such as a transformer will be considerably less. The authors seem to assume that the transformer in a truck must be transported upright. I have seen a big transformer in a special tank of the type shown in Fig. 2 transported on its side. This transformer was eventually shipped abroad. I should imagine it would be quite easy to take the ordinary shell-type transformer in a rectangular boiler-plate tank, provide it with a lifting cradle, and transport the transformer in the tank without oil in the same way. It is interesting to know that the authors consider that transformer manufacturers will be able to make any sizes of transformers required for the big turbo-alternator units which are now contemplated. The shell-type transformer has always appealed to me on account of its robustness. Even if it gets fairly rough handling after it is delivered on site there is much less chance of damaging the coils than in the case of the core type. It would be interesting to know what is the maximum voltage for which the authors are prepared to design shell-type transformers. On page 548 they mention 50,000 volts, but I am not quite sure whether that applies to the shell type or only to the core type. I should also like to know whether the costs given on page 550 are pre-war costs or present-day costs. With regard to the question of single-phase and three-phase transformers, personally I have a decided preference for the single-phase unit, particularly when it is of large size. One advantage which has not been brought out is that if we have a serious breakdown in a three-phase unit the probability is that the whole transformer is completely wrecked and the cost of the rewinding is considerably greater than it would be with a single-phase unit. I have always considered the water-cooled transformer of the cooling-coil type to be a makeshift arrangement. To my mind it is a very serious matter to introduce a water-cooling coil into a transformer, with the consequent possibility of leakage. In all water-cooling it is essential that the water should be at less pressure than the oil so that if there is any leakage it will be from the oil to the water. I do not see how that can be satisfactorily done with the water coil at the top of the transformer.

**Mr. H. S. Binns:** Although I agree with previous speakers regarding the very valuable information contained in the paper, there are many points on which I must disagree with the authors. Most of the points where I disagree have been covered by previous speakers, but there are one or two which have not been sufficiently brought out. A great claim is made for the robustness of the shell-type transformer. I assume that the authors are referring to the type shown in Fig. 12. In building up this transformer the coils, together with the insulation, are made up into a box-like formation, which is then turned on end and the core laminations built round it. A close study of the construction will show that the only means of support for the coils consists of the angle-iron supports H (see Fig. 12). This illustration, the authors inform us, is of a 7,000- to 8,000-k.v.a. transformer. In a transformer of this size there are roughly $3\frac{1}{2}$ tons of copper. This weight is entirely carried by the angle-iron supports H, which in turn are supported by bolts at each end marked K. There is no other support whatever for the coils; the side clamps B, C, D, under operating conditions do not come into play at all. Mr. Furlong has pointed out that the shrinkage in this type is quite as great as in any core-type transformer. Immediately shrinkage takes place, these clamps B, C, D, which the authors specifically state are not intended for taking up shrinkage, are no longer of service as a means of support. They might therefore, from the point of view of support, be left out. Their true function is to form abutments to prevent the coils splaying out on short-circuit. The method outlined does not appeal to me as a very rigid or robust construction. Further, the core laminations have no through bolts, being held in place with practically no compression by angle-irons on their outer edges, which are clearly shown in Fig. 19. As a test of robustness and rigidity I would suggest that the authors make the experiment of hanging the transformer by one ring bolt only; the distortion would probably be very considerable. This might easily

occur in handling due to the failure of an eyebolt or sling. I have seen a three-phase core-type transformer weighing over 14 tons hung up in this manner and no distortion resulted. My criticism of shell transformers refer to the type shown in Fig. 12 only, since it is quite possible to make a thoroughly rigid and robust shell transformer but not by the methods described and illustrated by the authors. The authors refer to the coil supports as bracing the coils. I would suggest that to brace the coils external support is required, particularly in the type referred to where the coils have what might be termed a one-point suspension. Mr. Cridge mentioned that external support is unnecessary with rectangular coils; this appears to me to be incorrect since I have seen a transformer of this type where the coils had burst on short-circuit. The authors claim it is much easier to obtain efficient circulation of the oil in the shell type than in the core type, reference being made to the pancake type of coil used in the shell transformer. In most up-to-date transformers of the core type the pancake coil is also used, so that what applies in the one case applies in the other with this difference: that whereas the distance blocks are rigidly held in position in the core transformer, this is not the case in the shell type shown in Fig. 12. In this case the distance strips are vertical (see Fig. 19) and are supported and kept in position by the coils. As previously pointed out there is no method of taking up shrinkage, so that these distance strips are liable to displacement when shrinkage takes place, as take place it will. I have seen cases with this type of transformer where the displacement which occurred was sufficient to allow the coils, distorted through lack of support, to come in contact with one another. Mr. Sills mentioned a possible danger in fixing springs of the type shown in Fig. 15 in the high-tension winding. The voltage across the springs is very low, and in any case no more difficulty could arise than in insulating the coils from the yokes.

Mr. J. F. Shipley: My first point is that something could be omitted from the summary of the paper. The last item but one, "women labour," is disposed of in five words. Transport restrictions are not mentioned at all. Exports restrictions are really import restrictions. The question of transport brings me to my second point. All papers of this sort which emanate from manufacturers and people who have to do with the designing of what is (more or less) standard plant should have something about packing. I have a lot of work to do in the way of going round and inspecting different material and I find there is nothing much to grumble about except the packing. Generally it receives attention from the chief packer, but never from the engineer. If manufacturers would get their engineers to design the packing a great improvement would follow. One or two speakers have mentioned the difficulty of shipping transformers in oil complete. It can be done very well when shipping from one big port to another big port, and when both such ports have quays where the transformer can be taken off the boat by a crane and deposited on a truck; but where it is necessary to tranship or to unload at sea separate packing cases must be used for everything.

Mr. W. Parry: Will the authors give some information in regard to transport along the roads on trucks? With regard to the radiator tank in Fig. 3, what is the effect of cutting off the radiating units half way up but still connecting to the bottom of the tank by means of a pipe? It seems to me that very wide ducts must be used on such tanks and transformers in order that a very large flow of oil may take place, as there is very small head causing the flow. The authors make comparisons between the single-phase shell types and the three-phase core types. Some information comparing them with the three-phase shell types would be interesting. I believe a three-phase shell type can be run with one phase broken down, provided that phase is short-circuited. I should be glad to know if that is so. The handling of very large units might be assisted by putting three single-phase units in one tank and so saving a certain amount of space. It would increase the interest of Table 4 if a column were added giving the total losses for each arrangement for the full 3,000 k.v.a. Only the details are given at present. On page 565 reference is made to the "ironclad" type of protective reactance, and this name is applied to the core-type construction. It would be better to call it "copper-clad," seeing that the iron is mostly surrounded by copper in that case. Some information as to the losses of such reactances would be valuable. I should like to join in the request that some information of a general nature be included relative to furnace transformers, showing the modern tendency in design. Mr. Sills suggested using lead alloy for the cooling worms of water-cooled transformers and that the pipes be put in parallel in order that there may be no joints inside the transformer case. I think this can be done with copper pipes just the same, getting rid of the joints in a similar way. Some time ago the *Electrician* published an account of experiences in regard to failure of large water-cooled transformers on the Rand. It was found that the pipe used had not been extruded correctly; in other words there were thin patches in the walls. These patches had been worn through by grit contained in the cooling water, which had run through and destroyed the transformer. That is a point which should be watched. With regard to the spiral spring in Fig. 15, it must be noted that the potential across the two faces of the spring is very small—only about 100 volts or so; consequently there is no difficulty or danger in having it in the middle of the winding. A previous speaker has stated that oil can be put along both sides of the coil in the shell type but that this cannot be done in the core type. Most of such coils are wound two sections together and separated simply by a washer so that the oil has free access to one side of each coil. In order to get the oil on both sides of each conductor it is necessary to separate the two sections by an oil duct; in other words, to use nearly twice as much space in ducts. It is entirely unnecessary because the conductivity of the copper across the small thickness of the coil is quite sufficient to prevent any appreciable temperature drop. The same thing applies exactly to core-type transformers, but there the spaces between the coils are radial, consequently the sludge can be

easily cleaned out of them, which cannot be done on the shell type. We shall not get over the sludge difficulty until such time as we have an insulation that will stand water. Then we can run the transformer in water instead of in oil, and allow it to work at 100° C. which would be the maximum temperature possible.

(*Communicated*): With regard to the shell-type construction shown in Fig. 12, it must be remembered that such a transformer has a distinct tendency to "rumble" internally when on load. This is due to the vibration of the conductors in the windings, and owing to the large number of ampere-turns in the coils it may be considerable. It can only be overcome by having the windings absolutely tight, and this can only be done with absolute certainty every time by means of adjustable clamps which act over the whole of the end-coil faces. In Fig. 12, the clamps shown only act on the part of the coil external to the iron core, and this causes the coil inside the iron to try to bulge out—the very thing one desires to prevent. On page 563 the authors give the force exerted over the face of the coil which is clear of the iron and which is easily taken care of by the clamping device in Fig. 12, but they do not mention the bursting stress in the conductors. Am I to assume that the authors consider it of small importance, since with the square box-type insulation shown it is practically impossible to put coil supports on the edges of the coils? In the case of the core-type construction they give the circumferential stress in the copper and, further, say that if it exceeds the elastic limit of copper, radial coil supports should be used. This is a matter which can only be calculated and I hope the authors will be good enough to add an Appendix giving the method of calculation. In connection with hoop stress it should be noticed that it is very difficult—if not impossible—to trace the true cause of a breakdown. If a short-circuit between turns develops in the windings, the copper at that point is melted, and it is quite possible that the hoop stress could easily burst open the coil. On the other hand if the coil bursts first, due to the hoop stress, a powerful arc is drawn out across the break and melts the copper, so that in effect the two cases are indistinguishable. A figure is also given for the axial stresses on a core-type transformer, on the assumption that the magnetic centres of the high-tension and low-tension are 5 per cent displaced. Such a large displacement should not be allowed. It may be due to the following causes: (1) faulty construction originally, (2) considerable shrinkage in one winding relative to the other, (3) tappings taken off at the wrong place. Cause (1) is of course within the control of the designer, who should make sure that the windings are symmetrical. Cause (2) may be obviated by the use of automatic adjustments for compensating for shrinkage. In this connection it will be noted that the arrangements shown in Figs. 13, 14 and 16, while compensating for the shrinkage do absolutely nothing to preserve the original symmetry of the coils, and thus as shrinkage occurs they automatically introduce the cause of abnormal strains in the windings. On the other hand the arrangement shown in Fig. 15 not only compensates for the shrinkage but preserves absolutely the original symmetry of the coils. Cause (3) is also within the control of the designer. For transformers on large systems the taps up to about 10 per cent of the full winding should be taken equally from the ends. Above 10 per cent they should be taken from the centre of the windings. If the voltage of the system is at all high it may be advisable to use only the latter method as it does not interfere with the specially reinforced end turns.

**Mr. W. S. Flight** (*communicated*): It has been mentioned by some speakers in the discussion in connection with the shell-type transformers recommended in the paper that the oil ducts between the coils are liable to become choked with sludge. I have seen a good many of these transformers dismantled and, strange to say, it is usually found that there is practically no deposit of sludge in these ducts even when the outer insulation has been heavily coated with sludge. The explanation of this is probably as follows. If transformer-oil sludge is heated in a test tube it is found that at about 80° C. the material will have melted and have become quite liquid. This means that any sludge which is deposited on a hot portion of the transformer will be removed when the temperature of that part of the transformer reaches about 80° C. Consequently, the tendency is for sludge to be depoisted on the cooler parts and its lodgment on the hotter portions is prevented. Another factor which probably influences the above is that sludge is deposited more on a horizontal surface than on a vertical surface; the convection currents through the ducts also prevent the lodgment of sludge. Whatever the explanation, the fact remains that provided a duct was initially free at both ends so that a complete circulation of oil could take place, practically no sludge is deposited. Reference has also been made to the desirability of drying transformers out in the factory before shipment. In this connection it must be realized that all fibrous materials very quickly re-absorb moisture. Unless the transformer could be placed in dry oil immediately after being dried out, the insulation will absorb moisture from the atmosphere and, in a climate such as this, may in 24 hours become as damp as before drying out.

**Mr. H. S. Holbrook** (*communicated*): As regards current-limiting reactors for feeders, which the authors mention towards the end of the paper, I am strongly in favour of the air-core type whenever possible. Reliability is the chief consideration with this class of apparatus, as it is called upon only occasionally to fulfil its function. When a short-circuit occurs the coil must be in perfect order. With the iron-core type and closely wound coils it is quite possible that a partial or incipient fault may exist unnoticed as long as the coil is carrying only normal current and developing but 4 or 5 per cent of the circuit voltage across its terminals. The existence of such a fault would be diasastrous when the short-circuit rush of current occurred. It is of primary importance therefore to have a reactor which is always open for inspection, and one whose insulation cannot deteriorate. The open construction of the air-core type also gives it the advantages of good ventilation and absence of hot spots, and the total absence of oil or fibrous insu-

lation with their attendant fire risks. I do not like the longitudinal bolts in the built-up concrete reactor shown in Fig. 21. I feel that there is a distinct possibility on a short-circuit accompanied by a high-voltage surge (which would reach its maximum across the terminals of the reactor) that an arc might jump from the terminal at one end to one of these bolts and from the bolt to the terminal at the other end, thus short-circuiting the reactor at the moment when it is called upon to act its part in protecting the system. I prefer the type * where the concrete frame is cast around the coil conductors, preventing any possibility of their relative movement. As regards the possible heating of structural ironwork, tests with such a reactor placed against the stanchions in an ordinary machine shop showed that the effects were not perceptible with the reactor at a distance from the stanchions of one-half its overall diameter.

**Mr. H. A. Ratcliff** (*communicated*): In connection with the overload rating of transformers, I am pleased to observe that the authors advocate the general acceptance of the British Standard ratings. Personally, I have never been able to understand why a transformer should be expected to withstand, say, a 25 per cent overload continuously. What this really means is that a purchaser obtains a 1,250-k.v.a. transformer rated as a 1,000 k.v.a. or else the makers supply one having a freak design, which may comply more or less with the overload temperature-rise requirements, but only by the sacrifice of desirable characteristics over the normal working range. The overload capabilities

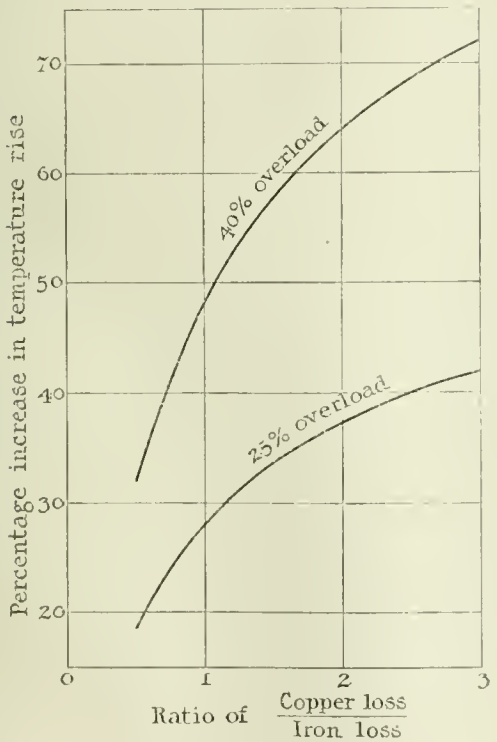



FIG. A.

naturally depend very much on the relative proportion of the iron and copper losses. I recently had occasion to investigate the effect of a 25 per cent continuous overload on several transformers, and for the purpose of comparison the incidence of the losses was most conveniently shown by means of the curve in Fig. A herewith. I have also added another curve which shows the corresponding effect for the case of the 40 per cent overload dealt with by the authors. Fig. 7 indicates very clearly the danger of an interruption in the supply of cooling water to large transformers, and it also serves to emphasize the advantages of ordinary oil-immersed self-cooled transformers in cases where periodic overloads of short duration are likely to occur. Table 5 is interesting, and apparently the calculations have been based on the actual average value of the load. In practice it may frequently be necessary to base calculations on the load factor, but in such cases it is necessary to take into consideration the actual shape of the load curve since the copper losses vary as the square of the load. Consequently, with a load factor of, say, 60 per cent, the actual load factor of the copper losses may be anything between 36 and 60 per cent, depending upon the shape of the load curve. Referring to the interlinking connections shown in Fig. 23, the star arrangement is undoubtedly the simpler, but if due regard is given to accurate "phasing out" and to the correct sequence of phase angles, there should be no inherent disadvantages with the ring method of linking up, and there is no doubt that purely from the interlinking point of view it possesses many practical advantages. With the star arrangement the responsibility attaching to the tie-bar or cable is very great. In practice the careful distinctive painting of all cable, cubicle, switch, and transformer terminals greatly facilitates correct "phasing out." In connection with the switching-in of transformers, the heavy current-rushes possible under certain conditions of magnetic history may be entirely avoided by the use of auxiliary charging contacts on the switches. Loose or chattering switch contacts are frequently the cause of excessive current surges, and I have actually known cases in which heavy current-rushes due to this cause were obtained when switching transformers *out* of circuit. The curves in Fig. 27 are extremely interesting and clearly indicate the effect of what is usually an unappreciated phenomena.

**Messrs. A. G. Ellis** and **J. L. Thompson** (*communicated reply*): In reply to Mr. Furlong, we do not agree that British manufacturers have had sufficient opportunities for supplying large units, but the state of things is now improving. We do not dispute the fact that three-phase units can be manufactured as well as single-phase units. The statements in the paper are the considered opinions of the authors after many years' experience in the manufacture of both types of transformers, and the remarks of various speakers confirm in the main those statements. Mr. Furlong's comparison between three-phase generators and three-phase transformers does not appear to us sound, since with a generator there is no practical alternative to the three-phase unit, while with the transformer a group of three single-phase transformers is possible in cases where it

* *Journal I.E.E.*, 1918, vol. 56, p. 289.

has distinct advantages. The statement that core-type and circular shell-type have great advantage over the shell-type shown in Fig. 12 is incorrect as regards cooling, for, as Mr. Sills remarks, each turn of each coil is in direct and constant contact with oil. For instance in the single-phase transformer, of which data are given in Table 2, there are 24 coils with an oil duct on each side. The axial width of any coil is not greater than 0·8 inch, which ensures a thoroughly uniform cooling. With reference to the possibility of sludge collecting in the ducts on the wave-shaped spaces, this does not occur as it is prevented by the continuous circulation of the oil either by forced circulation or by convection currents. In no transformer yet built to the authors' designs has sludging been reported or found in the ducts, and our experience covers a very large number of such transformers. Our reference to shrinkage being negligible in shell-type windings is based on our own experience and that of American manufacture, and we conclude that Mr. Furlong's experience in shell-type transformers has been less fortunate. Regarding springs for taking up coil shrinkage, we can only repeat the arguments in the paper which have been substantiated recently by the failure of a large core-type transformer of Continental manufacture fitted with springs as shown in Fig. 14, the reaction of the springs having allowed the coils to move on short-circuit with disastrous results. Had dashpots as shown in Fig. 16 been fitted, the sudden reaction due to instantaneous stress would have been prevented. Mr. Furlong claims that in the construction shown in Fig. 15 the magnetic centres of the primary and secondary windings will not be displaced by as much as 5 per cent of the winding length. We think he has overlooked the fact that the majority of transformers are provided with adjusting tappings for anything up to 10 per cent, which render it difficult to preserve magnetic symmetry. We are glad Mr. Furlong and other speakers support our suggestion for general adoption of the British Standard Rating for transformers, as this will give a common basis of rating and ensure uniformity in the matter of temperature and overloads. Regarding furnace transformers, these were omitted on account of the length of the paper, and this subject requires to be dealt with in a special paper.

In reply to Mr. Sills, paragraph (*a*) on page 549 refers to self-cooled transformers with tanks built complete in one piece. In Table 1 we give the limiting size as 6,000 k.v.a. 50 periods with tank built with detachable radiators. It is preferable to transport transformers standing in their natural position, and the case cited by Mr. Sills probably involved special transport conditions. Mr. Sills's reference to adequate ventilation agrees with the authors' opinions, and the inaccessible places and sunken pits in which some transformers are placed show want of forethought on quite an important point. The authors have found that the use of copper for cooling coils is the best practice on account of its reliability, high heat conductivity, and non-corrosive properties. Air-blast units are not generally recommended by the authors in place of self-cooled units except as giving economy of floor-space and cost. The efficiencies given in the paper are based on a temperature of 15° C., as this is the present usual standard with British manufacturers. Actually the temperature varies with the load so that no constant temperature basis is correct at all loads, but only serves as a basis of comparison. Regarding shell-type transformers, we do not favour the butt-jointed core on account of the more complicated construction, higher cost, and higher core loss. The time and labour required for dismantling and rebuilding a transformer with interleaved core joints, in case of repair, are usually rather exaggerated, and we find this outweighed by the advantages of the interleaved core mentioned in the paper. The authors have designed and built some large three-phase shell-type transformers, but such units become unwieldy and difficult to build and we generally recommend three single-phase units, with attendant advantages. We are glad to note that Mr. Sills supports our views of the efficient cooling of shell-type windings as against Mr. Furlong's criticism. Mr. Sills mentions the oil expansion chamber as a universal remedy for transformer ills. This attachment is now, however, generally regarded as quite superfluous except as an accessory to the use of inferior oil, for which purpose it was originally introduced by a Continental firm. The majority of transformer makers do not fit or recommend the oil expansion chamber, but prefer to specify a good-quality non-sludge oil. The difficulty of making and preserving an oil-tight joint at the tank cover and terminal bushings is not nearly such a simple matter as Mr. Sills would appear to believe, and oil leakage is not a desirable thing. Some form of expansion chamber or oil-trap is only justifiable in the case of tropical moist climates with large variation in night and day temperature to prevent moisture condensing in the tank. Even in this case, the usual form of oil expansion chamber is not adequate, and a sound practically air-tight transformer is probably a safer proposition.

Mr. Cridge is correct in his proportion of transformers shipped in oil, and 10 per cent is a fair if not a high proportion. The suggestion of the tank with a removable side is not new to the authors, but it presents manufacturing difficulties and would present difficulties on site. Its use would entail a very heavy and costly tank construction. The question of headroom would be better and more economically met by the use of a pit in which the transformer and tank could be lowered to floor-level before lifting out. The limiting size of a three-phase tank given in the paper for rail transport is based on the limiting loading gauges and on no other consideration. The rise in the curve of weight per kilovolt-ampere in Fig. 4*a* is due entirely to the rapid increase in weight of tank and oil quantity required for self-cooled units of large capacity.

The prices referred to by Mr. Watson are present-day prices at the date of the paper as near as it is possible to fix them. Oil-coolers, pipes, and pumping gear are included in the forced-cooled prices. The authors do not quite understand Mr. Watson's question as to cost and losses of extreme ranges of regulating transformers. The cost will depend on the percentage positive and negative boost required. The losses will be the same for the maximum and minimum boost, but will be a minimum for the mean voltage. The suggestion that transformers should be standardized is of interest to the

authors, who consider that sizes should be standardized, i.e. k.v.a. rating, also voltage ratios and frequencies, and in their opinion this is the only way to reduce manufacturing costs to a minimum and speed up production on an adequate scale. We would urge with Mr. Watson the importance of this matter especially at the present juncture, but it seems to us to be in the hands of the supply authorities to put the matter right. The question of earth shields is one that requires attention, and, in the authors' opinion, they are as great a danger to the life of the transformer as they are a safeguard to low-pressure machinery connected thereto. The most preferable protection is an earth connection on the low-tension side, either directly earthed neutral point or through an earthing transformer or through a spark gap, or static earthing device.

Replying to Mr. Williams, the load of a large transformer on a crocodile truck can hardly be considered to be a concentrated load, as may be seen from the dimensions appended to Table 1. On the question of prices we have already replied to the same query by Mr. Watson. Regarding the maximum voltage of shell-type transformers, these have been built, in America, up to 250,000 volts' working pressure. In such transformers the question of impedance voltage required, detailed design and construction of the coils and insulation also govern the choice of type and usually give preference to the core type with circular coils.

In reply to Mr. Binns's criticisms of the shell-type constructions illustrated in the paper, we need only say that, were these criticisms founded more on fact than fiction, many hundreds of such transformers, totalling hundreds of thousands of kilovolt-amperes, in this country and America, would never have emerged from the factory or have been in continuous and satisfactory operation for many years with only a very small percentage of trouble. The designs illustrated by the authors are laid out to deal with all the stresses put on the transformer, both during handling and during operation, and many years' experience with this type is quite adequate to support their opinions, though a little more constructive criticism from this speaker might be useful. The question of shrinkage is also covered by the above statement and the arguments in the paper. We have met cases of radial distortion of shell-type windings, at the parts of the windings not encased in the core. Such damage has been due, not to the stresses under a normal short-circuit, but to a short-circuit of a part of the coil between two tappings when a few turns have had to stand the whole of the shock. If Mr. Binns can produce a transformer which will stand up to such an occurrence it will be welcomed.

With reference to Mr. Shipley's remarks, we regret that the length of the paper prevented us dwelling further on the points he mentions. We agree with him that the question of packing is an important one, especially for export.

In reply to Mr. Parry, with reference to Fig. 3 it is known that the bottom parts of the radiators do not radiate much of the heat, as the oil is practically cold at the bottom of the transformer. These radiators are, however, usually made to extend nearly the full height of the tank to ensure the best circulation of the oil. With regard to the matter of sludging of oil we emphasize the two precautions—a good-quality non-sludge oil and plenty of liberally proportioned oil ducts in the windings. Most of the points in Mr. Parry's communicated remarks have been already dealt with. Rumbling or humming in a shell-type transformer is due to magnetic vibration of the core and not to vibration of the windings.

Mr. Flight's communication disposes of a number of speakers' fears (though apparently not experience) regarding collection of sludge in the oil ducts.

Mr. Holbrook's remarks, we are pleased to note, substantiate a number of the points we have touched on. Regarding the protective reactances, there is no reason to suppose that an iron-clad oil-immersed reactance is not reliable as compared with the air-core type. The iron-clad reactance is, if anything, more reliable than a transformer and many such reactances are in operation. In the paper we have endeavoured to state impartially the pros and cons of each type.

Mr. Holbrook is in favour of the air-core type reactance for feeder work and so are the authors, not from the point of view of reliability, but from point of view of cost, as an iron-clad reactance is as reliable as any other type and in the authors' opinion more compact.

Mr. Ratcliff appears to be in general agreement with the authors' views on rating and overloads. Water-cooled and artificially cooled transformers should be given special attention when overloaded, as an interruption of cooling auxiliaries would soon lead to disastrous results.

## North-Eastern Centre, at Newcastle, 17 March, 1919.

Mr. A. A. Hughes: The portion of the paper which appears to call for most comment is Section 4, as the question of cooling of transformers has become increasingly important with the growth in capacity of individual units. In considering the type of cooling to be adopted, it should be borne in mind that for forced cooling continual attendance is not absolutely necessary, even though it be desirable. On our system, we have forced-cooled transformers in substations which are situated some hundreds of yards away from the nearest power station, and which are only visited once, or perhaps twice, during each shift. To overcome the danger of damage occurring due to a stoppage of the oil or water pumps, we install in each transformer two thermostats—one for the temperature alarm which operates a buzzer in the power station when the temperature of the oil reaches 80° C., and the other for tripping the transformer switches, should the temperature reach 90° C. A prolonged trial of these thermostats has proved them to be thoroughly reliable. The figures given under the heading of "cooling" in Table 2 were, I presume, not obtained under working conditions, and it may therefore be interesting to consider some actual results obtained

locally. The figures submitted are made additionally interesting because they refer to a set of three 2,000-k.v.a. single-phase transformers which step up the pressure to 20,000 volts, and to a bank of two 3,500-k.v.a. three-phase transformers which step down the pressure again to 6,000 volts at the far end of the line. The two three-phase transformers whose combined losses amount to 80 kw. are cooled by three 40-kw. thermoplate coolers, which take 16 gallons of water per minute. The maximum load dealt with is 6,000 kw. with a load factor of 78 per cent. The water inlet temperature is 15·5° C., outlet 24·4° C., oil inlet 47·2° C., and outlet 41·6° C. The three single-phase transformers are cooled by two 40-kw. thermoplate coolers, and in this case 30 gallons of water per minute are required, the total losses being 55 kw. Water inlet here is 13·3° C., outlet 20·5° C., oil inlet 55·5° C., and outlet 49·4° C. The temperature of the atmosphere in both cases was 17·7° C. It will be noticed that the cooling apparatus consists of a number of small units. This allows of a cooler being cleaned whilst the transformers are in use, and although the initial cost is about 20 per cent higher, the facilities accruing, looking at it from the point of view of maintenance, are well worth the additional capital outlay. I might mention that it will be found to be an extremely difficult matter to obtain oil-tight glands on both pumps and valves with an oil pressure of 30 lb. as mentioned by the authors, and a much lower water pressure should be used. The difficulty of handling large tanks has been referred to by the authors, and this together with the problem of cooling big transformers may eventually be solved by shipping cores only and placing them in concrete pits lined with, say, sheet steel to promote radiation. With regard to self-cooled transformers, I agree that good clearances are necessary between the tank and the chamber wall. The figures given by the authors are on the small side, and I suggest that a convenient method of gauging the distance is to allow a clearance all round equal to half the width of the transformer tank. In Section 4 (*b*) the authors appear to show a decided preference for shell, as against core type, and consequently for single-phase as against three-phase, though in so doing they are not consistent, as they first of all state that there is little to choose between the two types. The efficiency of a three-phase transformer is higher, and its capital cost is lower than a group of three single-phase transformers. It seems to me to be a confession of weakness to say that the single-phase transformers have any advantage over three-phase, from the point of view of continuity of supply, or of spares, for, after all, a three-phase transformer should not require any more thought from that particular standpoint than a three-phase generator. Substation transformers should be of the core type to facilitate repairs. Spare coils kept at the central store could be fitted in case of breakdown inside 24 hours, whereas a broken-down transformer of the shell type has almost invariably to go back to the makers for repairs. A further disadvantage of the rectangular shell type, as shown in Figs. 12 and 19, is the difficulty of cooling, as the coils are not in direct contact with the oil. The wave-shaped distance pieces which form the oil duct in the transformer illustrated in Fig. 19 will in time become blocked up with sludge, and consequently the iron will become overheated. Furthermore, it would be difficult to clean the channels on account of their shape, and this appears to be yet another argument in favour of core-type transformers, which have large and straight oil ducts. With regard to the question of adjustable coil supports, the authors show four methods of taking up shrinkage. None of the arrangements are very sound, and I think there is need for considerable development. The arrangements shown in Figs. 13, 14 and 16 are very similar, and make satisfactory provision for compensating for shrinkage; but they fail to compensate for the movement of the coils which takes place at the moment of short-circuit. The arrangement of springs shown in Fig. 15 is mechanically good, and has not the same objection to which I have just referred. The chief objection to this type is that in case of repairs it is necessary for the transformer to be returned to the manufacturers, as the springs cannot be replaced except at the makers' works. I think it is extremely doubtful whether all the time and money that has up to now been spent on adjustable coil supports is in any way proportional to the results obtained.

**Mr. G. N. Wright:** Reference is made to transformer tanks fitted with external cooling tubes or radiating pockets; these tubes or pockets are very liable to sludge and are very difficult to clean, though the boiler-plate tank with external cooling tubes makes what is probably the strongest mechanical job where an external oil flow is necessary. Mention is made of single-layer spiral windings of copper strip wound on edge. Do the authors think this is a sound proposition for small and medium-sized transformers? I have had experience of one such transformer—600 k.v.a. 11,000/440 volts—which broke down twice due to faults between adjacent turns and was eventually entirely rewound in a different way. It seems that for both mechanical and electrical reasons the thin strip is difficult to insulate owing to its sharp edges. What is the smallest capacity of three-phase 11,000-volt transformer on which this type of winding could be recommended? I rather agree with the authors that automatic adjustment of the windings is not ideal, and I think that tightening up of the adjusting bolts at fairly frequent inspections is a sounder idea. Note is made that the axial stress may amount to 200 tons per leg between high-tension and low-tension concentric windings on a 5,000-k.v.a. three-phase core-type transformer. Is it in the authors' opinion worth the trouble and expense of keeping the magnetic centres of the windings the same by making each tapping affect both ends of the limb equally, and making the adjusting bolts tighten equally from both ends? Mention is made of a new type of magnetic shunt of multiple-gap construction designed and patented by the authors. I have heard of a magnetic shunt of the old type on a transformer for supplying a rotary converter giving considerable trouble due to excessive heating. Is the new type of shunt entirely free from this trouble?

**Mr. R. M. Longman:** One is immediately struck in this paper by the attention which has to be paid

to the limiting sizes as determined by transport, but I should like to draw the authors' attention to the question of transport by airship, which in a few years should be quite feasible and may possibly be a commercial proposition that would at once do away with the question of trucks, gauges, and tunnels, etc. I note that the normal rating allows for a 50 degree C. rise with a maximum air temperature of 40° C, that is, an actual temperature of 90° C. on the transformer. Is this not rather high for the iron and likely to lead to increased iron losses? I should like to know whether the authors have carefully examined the iron from transformers which had been subjected to considerable overload, or which had been much overheated and in which the iron losses had greatly increased, and have subjected the iron to chemical, physical, and magnetic tests. I have had occasion to obtain the iron losses of several transformers which had been getting decidedly too hot, and in two cases the iron losses were increased 50 per cent, one being a comparatively new transformer which had certainly not been overloaded. With reference to the spring coil for taking up the shrinkage of windings, have the authors seen any case in which a transformer so fitted has been called upon to withstand a really first-class fault? The arrangement shown in Fig. 15 appears to be the best, and it would seem advisable to arrange for the tightening up of the coils of any core-type transformer to be done in a rather similar manner, that is, to have clamping nuts about the centre of the coils, clamping the coil against the top and bottom, thereby holding them more effectively. I should also like to know the flux density which the authors suggest such transformers work under and what they consider to be a reasonable magnetizing current for such flux density. Large power transformers which I have had occasion to test have shown considerable variation in the magnetizing current when considered as a percentage of the full-load current. In one transformer it was only about 2 to 3 per cent, the power factor being above 0·5, while in another, by the same maker, the magnetizing current was about 12 per cent and the power factor extremely low, as one would expect.

**Mr. J. R. Beard:** While I am in general agreement with the authors' views there are several points which I should like to amplify. As regards transportation, while road transport is admittedly tedious and unsatisfactory it must not be overlooked that bulkier apparatus can be handled in this way than by rail. I also think scarcely sufficient prominence has been given to the importance of being able to transport tanks by road and rail without risk of subsequent oil leakage. The boiler-plate tank with cooling tubes was originally developed to meet these conditions, but recent improvements in corrugated tanks such as welding on the bottoms thicker plate and heavy cross-bracing have largely overcome the earlier troubles. When reference is made to the use of detachable external radiators, it should be pointed out that they introduce a large number of joints which require to be made perfectly oil-tight (which is a different thing from water-tight) and also such radiators are liable to sludge up completely if poor oil is used. Perhaps the authors would add some reference to tank design for outdoor transformers. A 3,000-k.v.a. transformer has recently been erected in the open air in the Middlesbrough district, the high-tension cables being brought to the terminals through special sealing bells with their insulators dipping below the oil level in oil boxes welded to the sides of the main tank. The various tapping connections are made inside the oil boxes. Are the curves in Figs. 4 (*a*) and 4 (*b*) based on present-day prices and does Fig. 4 (*b*) include the cooling gear? I am not quite satisfied with the comparison given in Table 4. In the first place it is not stated whether a duplicate or non-duplicate supply is being catered for; secondly, the important items of building accommodation and switchgear are omitted; and thirdly, any large undertaking will not require a complete spare transformer at each substation. A common spare for each size of transformer will be kept at a central store and the cost of such spare can be omitted from the comparison in question. I suggest the authors should compile a new table on the basis that (1) the supply is required in duplicate; (2) in case of breakdown to one transformer the remainder can be run, while a spare is being installed, at a higher temperature than is advisable for continuous use; (3) buildings and switchgear are included; (4) a spare is assumed available at the stores in case of breakdown. A similar comparison for a non-duplicate supply would also be of value. With regard to Fig. 7, additional information is desirable as to the permissible period for severe short overloads, i.e. twice to four times normal load. Experience shows the need for automatic means of rigidly taking up shrinkage, as constant attention to tightening clamps is very difficult in practice. I am therefore very interested in the method shown in Fig. 16, which was described to me some years ago but which I am not aware has been commercially developed. Too much importance cannot be attached to ample bracing of the coils. It is now nine or ten years since a series of elaborate experiments were carried out at Dunston power station on several specially braced types of transformer. These were directly short-circuited across two 8,000-kw. turbo-alternators and on the whole the results were reassuring. The maximum size of transformer, however, was about 600 k.v.a., and I do not think that the fact that the stresses are roughly proportional to the square of the capacity has been fully realized in the design of later transformers of larger size. I am afraid Table 7 tends to give a fallacious sense of security. Theoretically the factor of safety on the insulation between turns may be enormous but, nevertheless, the greater proportion of transformer failures in practice occur through faults between turns. This type of failure is especially objectionable because no commercial form of automatic protective gear will disconnect such a faulty transformer until the fault has burnt through to earth or through the insulating cylinder to the low-tension windings. The causes of faults between turns are rather obscure since the subsequent damage usually destroys all the necessary evidence. Another feature in connection with insulation to which more prominence should be given is the insulation of tappings. These

are very liable to give trouble even when they are not situated adjacent to the phase terminals. I remember one case in particular where a large 20,000-volt star-connected transformer had tappings at the neutral point. While the inner tappings were in use, switching on the system caused a flash-over from the free open-ended tappings to the inner tappings and shattered the insulators. As showing the peculiar effects which may occur with short open-ended circuits, Mr. Vernier described to me recently the shattering of insulators on 20,000-volt overhead lines at road crossings. The conductor was duplicated across the road as shown in Fig. B, and flash-overs took place between B and C which shattered the insulator and produced a fault on the line. I should like to correct quite a common misunderstanding, to which the authors rather lend colour by their suggestion that adjustable reactances should be used for equalizing loads between feeders. This is a most inefficient method as compared with the use of induction or other forms of voltage regulators, the reason being that the insertion of reactance in one leg of a parallel circuit produces a phase displacement

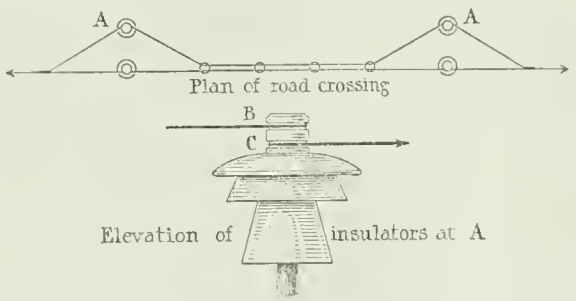



Fig. B.

between the currents in the parallel paths, with the result that the arithmetical sum of the several currents is greater than the total resultant current. The resistance losses are correspondingly increased, and it can be shown mathematically that it is equally as inefficient to regulate the load between parallel feeders by reactances as by resistances. The adjustable split-conductor reactance illustrated in Fig. 24 was built for use on a feeder from Dunston power station but the conditions were quite special as it was for use with a very short feeder crossing the Tyne and joining up with a system on the other side which had previously been fed in a roundabout way over the available bridges. A reactance was necessary in any case to limit the short-circuit current at the substation end of such a short feeder, and it was convenient to make this adjustable to avoid the use of a voltage regulator in addition. In dealing with the use of auto-transformers for interlinking I was surprised to note that they are specially recommended where the difference of voltage is small. I have always understood that under these conditions it was particularly difficult to make an auto-transformer stand up to a heavy short-circuit. The special form of magnetic shunt for high-reactance transformers which the authors have introduced is an important improvement. I have known several cases of rotary transformers with the older forms of magnetic shunt which, when opened out, showed serious evidence of overheating on the low-tension windings and the insulating cylinder. In fact I do not recommend operating engineers to add to their anxieties by too detailed an investigation of the internal condition of many of their apparently sound rotary transformers. The authors' statement that the new construction saves 0·2 per cent in efficiency shows the danger of overheating with some of the older constructions, since it is equivalent to over one-tenth of the total transformer losses and occurs in a localized form and in a position where overheating is very liable to cause trouble. In dealing with the influence of war conditions on transformers the authors omit what has been to me the most striking effect, viz. the very great increase in cost as compared with other engineering plant. The only item which I know to have increased by a greater percentage is the cost of trenching for cables, and this is understandable as it is entirely carried out by rough labour.

**Mr. H. G. A. Stedman:** From the authors' figures it would seem unnecessary to build single units beyond sizes which can be at present sent by rail even for large power stations. For general substation working, the slight improvement in efficiency with transformers (self-cooled) over 3,000 kw. is more than counterbalanced by the great difficulty and expense of maintenance and repairs. Excellent results are obtained with external water cooling of the oil, and oil pressures up to 30 lb. can be maintained with careful packing. From the point of view of rapid repairs and maintenance of supply on large networks there is, in my opinion, no comparison between the core and shell type of construction, the former being much superior and scarcely less liable to breakdown. Moreover, the form of wavy oil duct shown on the screen becomes filled with sludge in time and cannot be cleaned out. With regard to shrinkage of windings on the core type, we find that by systematic overhaul of transformers (at present the period is two years) this can be followed up and other defects such as bad connections, loose nuts, and defective bushings on the core-clamping bolts rectified at the same time. The winding of copper strip edgewise is to be deprecated for mechanical reasons. Can the authors give any satisfactory reason why so many transformers break down between adjacent turns, the proportion being in the neighbourhood of 70 or 80 per cent of the total failures? Faults to earth are comparatively rare, except when caused by external short-circuits straining or bursting the windings. This has been going on for a number of years and war conditions cannot in many cases be blamed for it. With regard to tanks, any form of wing radiators or cooling tubes should be designed with ready access for cleaning, as it is surprising how a thin film of sludge will raise the core temperature, and with most oils this has a cumulative effect. The bases of tanks should be carefully designed with a view to easy movement on rollers. I find the latter are far superior to wheels in most cases where heavy transformers have to be moved from the crane or shear-legs into position. It is surprising to find this point overlooked. Recently some 1,500-kw. self-cooled transformers were supplied by a British

maker, the base casting having projections underneath which made rolling almost impossible and added considerably to the cost of the erection, there being (as is so often the case) no crane available. In section (11) the authors advocate switching transformers in "slowly" to avoid the heavy rush of magnetizing current; but from all the evidence one has been able to collect and from personal experience, with both hand-operated and remote-control switchgear, there is little justification for this assumption. It is also not very apparent on what grounds the authors assume that by "slowly" closing a high-pressure oil switch the three phases of a transformer will be simultaneously charged at maximum potential. There would always be the danger of switch contacts welding-up and preventing the switch from tripping; the upkeep of contacts on a large system is a considerable item and the safety of operators would have to be considered before making such a rule. The erection and drying-out of large transformers is a very important matter, and where the purchaser has a skilled staff it is preferable to lift, examine, and dry-out the coils on site, as it is usually a risky proceeding to put transformers on load as received by carrier. This of course does not preclude drying-out by the makers for the purpose of the works pressure and over-potential tests.

Mr. S. A. Stigant: I had occasion a short time ago to investigate theoretically the effect of the relative proportion of iron and copper losses on the efficiency, temperature rise, and overload capacity of transformers, and extending the results obtained I find that the authors' statement on page 556 that "A transformer designed for maximum efficiency has the iron loss about equal to the copper loss, which condition should be thus fulfilled at $\frac{3}{4}$ load to full load," is not correct. Fig. C herewith shows the extent to which the efficiency is affected by various proportions of iron and copper losses, the curves embracing a range of the ratio, iron to copper loss, of from 0·33 to 3·0. The proportions given occur at full load and the sum of the iron and copper losses remains constant. It will be seen that maximum efficiency for the particular case of iron loss equal to copper loss occurs at full load, but that the value obtained is the lowest point on the dotted maximum efficiency curve. As the ratio of iron to copper loss either increases or decreases in its departure from 1 : 1, the maximum efficiency increase being reached (with the various ratios) at overload values and high temperatures in the former case, and at fractional loads and low temperatures in the latter. In cases therefore where a transformer may be expected to operate continuously between 0·7 load and full load the ratio of iron to copper loss may be between 0·5 and 1·0 if average maximum efficiency is desired. From Fig. C it would appear that the differences in maximum efficiencies at the various iron to copper loss ratios are such as to warrant this particular aspect of the loss ratio being ignored, while more attention might be given to its influence on the actual efficiencies obtained at fractional loads and overloads. Of considerably more importance, however, is the effect of the loss ratio on the temperature rise and overload capacity of a transformer. As is generally known the majority of the transformers in this district have been designed and built to comply with the requirements of a 50 per cent overload at 65 degrees C. maximum temperature rise, while at normal full load the temperature rise must not exceed 40 degrees C. Fig. D shows the effect of the loss ratio, considering the two temperature-rise conditions separately. In all instances the loss ratio specified is that obtaining at normal full load and at the actual full-load temperature rise. The air temperature has been taken at 15° C., which represents a fair average figure for a modern design of well-ventilated transformer substation. The curves have been calculated on the assumption that the temperature rise is directly proportional to the total losses, and they have also been corrected for the

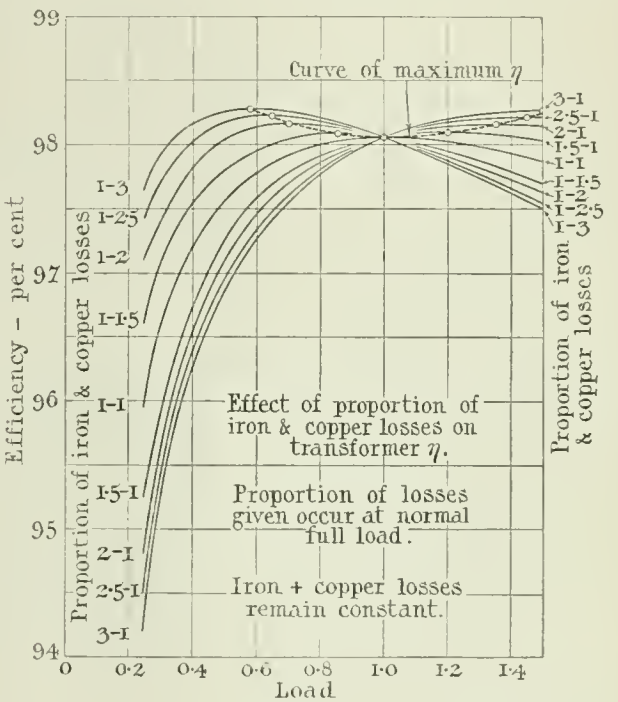



Fig. C.

increase or decrease in copper loss due to variation in resistance with temperature. It will be seen that if the transformer is designed actually to give a temperature rise of 40 degrees C. at normal continuous full load, to obtain a 50 per cent overload within the 65 degree C. temperature-rise limit the ratio of iron to copper loss must be greater than about 1·3. Ratios less than this produce excessive temperatures at the higher overloads, and unnecessarily low temperatures at fractional loads. If, on the other hand, a transformer is designed primarily to meet the overload conditions, a loss ratio of 1 : 1 will give a temperature rise of approximately 37·5 degrees C. at normal continuous full load, while a selection of any of the loss ratios less than unity, i.e. down to 0·33, will enable the transformer to meet the guaranteed normal full-load temperature rise. While, speaking generally, it can be said that a loss ratio of 1 : 1 gives good average

results, cases may often arise which, as suggested by the authors, can only be dealt with on individual merits. In the case of large concerns such as the North-Eastern Power Companies, having over 1,000 power transformers in service, changes are often being made in the location of transformers on the network in order to utilize their full output, and with the various load conditions under which a transformer may have to operate (due to such change of location) it appears to me that, however theoretically desirable it may be to consider the effect of iron to copper loss ratio on the annual charge for losses, from a practical standpoint and under such conditions there is little need for specifying any particular ratio of losses. In connection with the annual charge aspect it is worthy of note that the temperature rise and overload requirements above referred to, that is, 40 degrees C. temperature rise at normal full load and 65 degrees C. rise at 50 per cent overload, are quite compatible with the idea of minimum annual charges when the transformers are designed primarily to meet the overload conditions. Coming next to the question of reinforced end-turns,

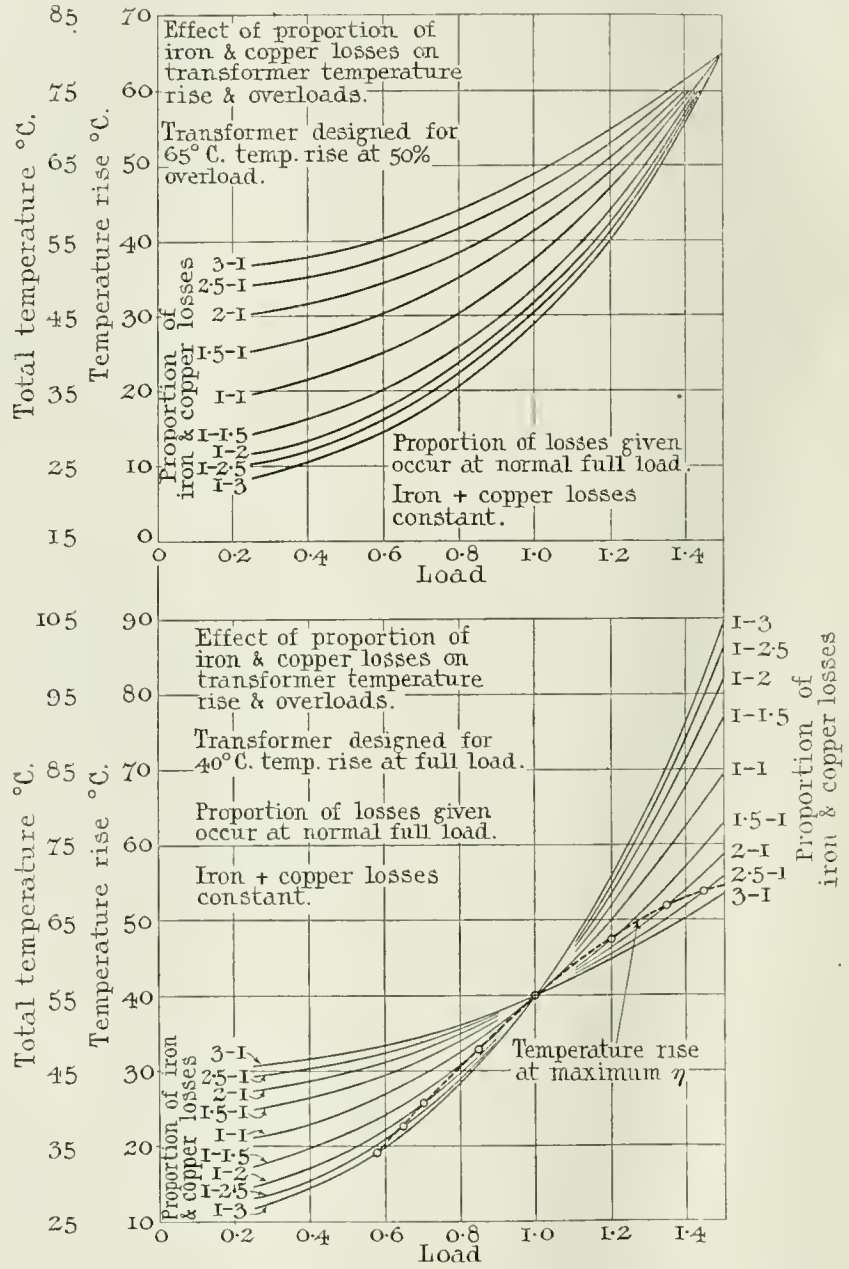

Effect of proportion of iron & copper losses on transformer temperature rise & overloads.
Transformer designed for 65° C. temp. rise at 50% overload.
Proportion of losses given occur at normal full load.
Iron + copper losses constant.
Total temperature °C.
Temperature rise °C.
Load
Proportion of iron & copper losses
3-1
2·5-1
2-1
1·5-1
1-1
1-1·5
1-2
1-2·5
1-3
Effect of proportion of iron & copper losses on transformer temperature rise & overloads.
Transformer designed for 40° C. temp. rise at full load.
Proportion of losses given occur at normal full load.
Iron + copper losses constant.
Temperature rise at maximum η
Proportion of iron & copper losses

FIG. D.

although the authors are unquestionably right in calling attention to the more arduous service, so far as abnormal voltage stresses are concerned, to which transformers directly connected to overhead lines may be subject, they rather leave it to be inferred that if the overhead line is replaced by an underground cable "the end-turn reinforcement is less important" practically to the extent of negligibility. This is not the case however; for high-voltage and high-frequency

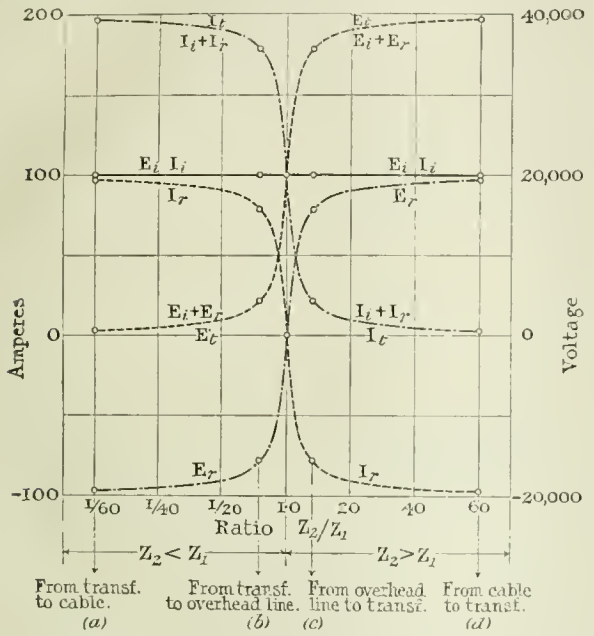



FIG. E.

transients are also engendered by switching, short-circuits, and earths. An oncoming travelling wave on reaching a transition point, or point of change of surge impedance, in a compound circuit becomes partly reflected and partly transmitted. Where the surge impedance $Z_2$ of the second portion of the circuit is smaller than the surge impedance $Z_1$ of the first portion, voltage reflection takes place with a change of sign, and if the original disturbance produced a train of waves the resultant voltage wave in the first portion of the circuit would have a small amplitude, being the difference between the incident and reflected waves. The amplitude at the actual transition point would have this value whether the original disturbance was a train or single impulse. The transmitted voltage wave has the same amplitude as the resultant wave at the transition point. If the conditions are reversed, that is $Z_1$ being smaller than $Z_2$, the voltage is reflected at the transition point with the same sign as the incident wave, the resultant wave in the first circuit being greater than the original incident wave. The transmitted voltage wave of course again has the same amplitude as the resultant wave at the transition point. In applying these principles to a transformer connected to either a cable or an overload line we can take the following average values for surge impedances at high frequencies:—Transformer, 3,000 ohms; overhead line, 350 ohms; underground cable, 50 ohms. Four different cases present themselves of a travelling incident wave passing from:—

(*a*) Transformer winding to underground cable.
(*b*) Transformer winding to overhead line.
(*c*) Overhead line to transformer winding.
(*d*) Underground cable to transformer winding.

Fig. E shows the variation in amplitudes and signs of the different component waves involved when the ratio of $Z_2/Z_1$ ranges from 1 : 60 to 60 : 1, assuming that the amplitude of the incident voltage wave is 20,000 and of the current wave 100 amperes. The positions of the above four cases are indicated on the chart and it will be seen that whether a disturbance originates in the transformer or in the line the amplitude of the phenomena at the transition point (transformer end-turns) is very similar when either an underground cable or an overhead line is directly connected to the transformer. When the disturbance originates in the transformer windings a slight advantage as regards voltage amplitude at the transformer terminals lies with the cable; when arising in the line, the overhead line is slightly more favourable. The following table gives the actual figures corresponding to the four cases quoted above, and Figs. F and G show the space distribution of the voltage and current waves in their relation to the curves of Fig. E. In the table and in Figs. E, F, and G, E and I stand for voltage and current respectively, while the subscripts have the following significance:—

$i$=incident waves
$r$=reflected waves
$t$=transmitted waves.

TABLE.

| Case | $\frac{Z_2}{Z_1}$ | Voltages | | | | Currents | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $E_i$ | $E_r$ | $E_i+E_r$ | $E_t$ | $I_i$ | $I_r$ | $I_i+I_r$ | $I_t$ |
| (*a*) | 1/60 | 20,000 | — 19,350 | 650 | 650 | 100 | 97 | 197 | 197 |
| (*b*) | 1/8·6 | 20,000 | — 15,800 | 4,200 | 4,200 | 100 | 79 | 179 | 179 |
| (*c*) | 8·6 | 20,000 | 15,800 | 35,800 | 35,800 | 100 | — 79 | 21 | 21 |
| (*d*) | 60 | 20,000 | 19,350 | 39,350 | 39,350 | 100 | — 97 | 3 | 3 |

Deformation due to dielectric and copper losses is neglected. As the transient effect of switching, short-circuits, earths, and resonance are generally known and appreciated and are not confined to overhead lines, the above remarks and figures indicate that all power transformers, especially of the large sizes referred to in the paper, should have amply reinforced end turns irrespective of whether they are to be connected direct to an overhead line or to an underground cable. It should also not be forgotten that a cable represents a shunt capacity con-

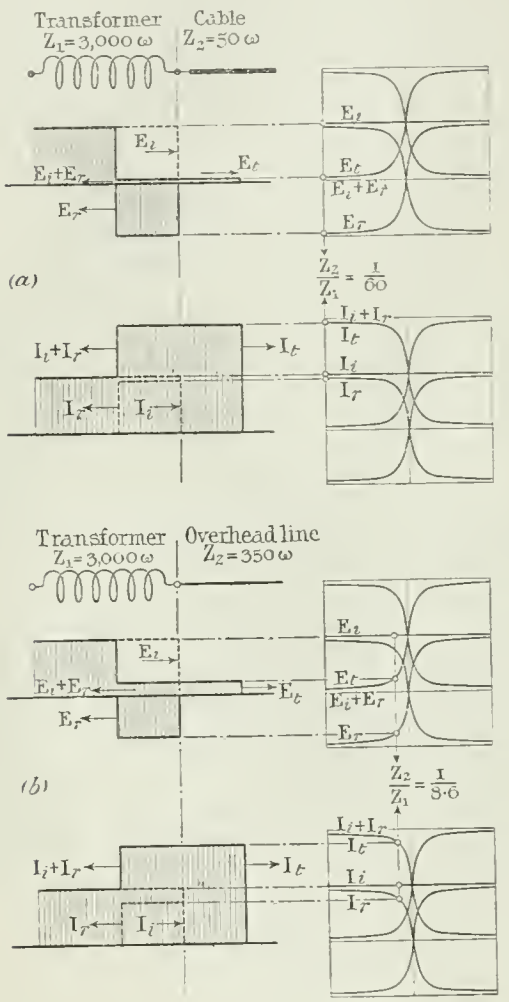



Fig. F.

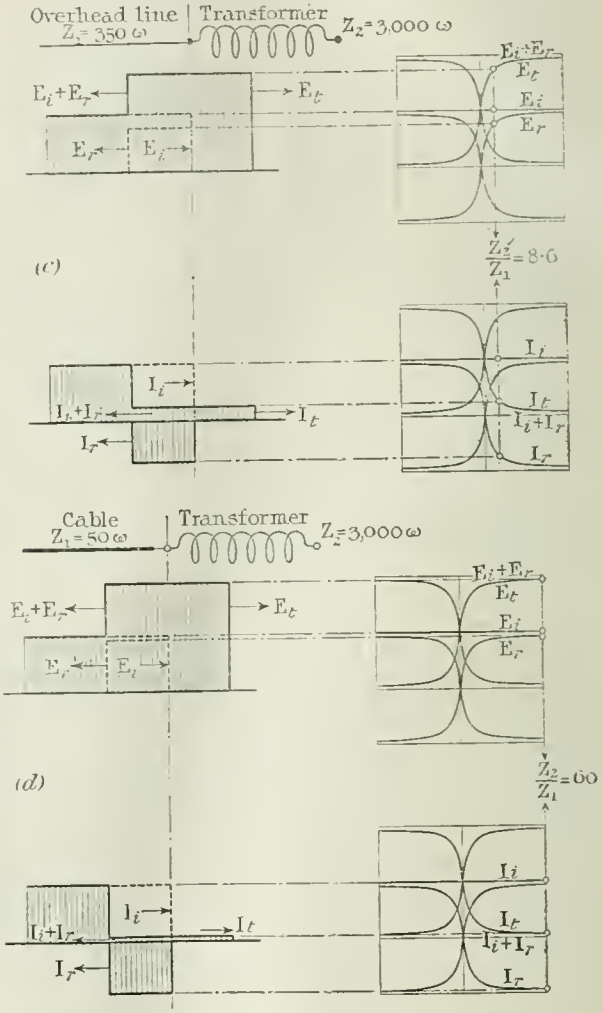



Fig. G.

nected across the transformer terminals and earth, and as this will generally be larger than the series capacity between turns, the result will be in case (*d*) to produce across the end turns a further concentration of voltage than would occur with an overhead line, case (*c*). Reinforced insulation, if used at all, should, I consider, also be applied to the "starred" end turns of star-connected transformers, while the links forming the neutrals should be heavily insulated to withstand possible high-voltage standing waves which may build up at the neutral point. Where high-tension tappings are provided, resulting in certain portions of the windings being left open-ended, these open ends should be safeguarded by reinforced insulation, as they constitute a reflection point where voltages may build up to approximately twice the value of the incident wave. The percentage reinforcements given in the paper appear to me to be very inadequate and where at all necessary should, I consider, not be less than 5 per cent at each point of application. I should like to know the extra cost involved for end-turn reinforcement for representative outputs and voltages and whether there is much difference in respect of this between core- and shell-type transformers, specifying at the same time the expected performance of the insulation. As end turns are reinforced to withstand high-frequency voltages it seems that Fig. 18 should be based on high-frequency characteristics of the insulation and not on voltages at normal frequencies. In order to determine such characteristics, sample coils might be wound under the usual manufacturing conditions and their insulation tested with a high-frequency oscillator or built-up oscillating circuit. I am convinced that much more serviceable results would thereby be obtained. I think it would be very

interesting if, in their published reply, the authors would give curves showing the relative influence of the same values of internal and external reactance on the limitation of the mechanical stresses on the windings of a transformer when under balanced and unbalanced electromagnetic conditions.

**Mr. H. W. Clothier**: A point of extreme national importance at this critical stage of the industry arises out of the opening and concluding remarks in the paper. It is stated that "to-day the order of size of unit for large stations is from 15,000 to 50,000 kw.," which "has led us to generation voltages up to 11,000 volts," and that "while British manufacturers have had ample opportunities of taking a front place so far as large turbines and generators are concerned, equal opportunities have not been afforded in transformer and switchgear work." This is misleading. In this country ample opportunity has been afforded for the development of both transformers and switchgear on schemes with even larger generating plant capacity for a number of years. The aggregate plant capacity running solid on one network on the North-East Coast for many years has been in the neighbourhood of 200,000 k.v.a. and plant has been installed, or is now in hand, for much heavier services. No doubt the authors intend their remarks to refer only to the very high transmission voltages, but even so the experience gained with 20,000 volts in this country is very sound and extensive. I understand it is due to an unfortunate oversight that in the advance proofs of the paper no reference was made to the North-East Coast power companies, although the help of one American and two Swiss firms was formally acknowledged. The facilities afforded by the requirements and the experiences of this district have been of great value to British manufacturers. At these times when such big things are before the public it is necessary that we neither belittle our own competence, nor engender unfavourable impressions at home and abroad as to the source and extent of our experience.

**Messrs. A. G. Ellis and J. L. Thompson** (*communicated reply*): The authors are interested in Mr. Hughes's experience with cooling plant and the figures he gives. If transformers are fitted with temperature alarms and temperature cut-outs, it is of course not essential to have the transformer plant under continual observation, but nevertheless an attendant must be close at hand, even if not in the same building, so that immediate attention may be given to the plant in case of need. The figures in Table 2 were arrived at from calculation and tests, and are practically the same as would be present under normal working conditions. It will be noticed in Table 2 that the authors suggest three coolers per group, which agrees with Mr. Hughes's practice and allows of the possibility of one cooler being shut down and cleaned without interfering with the supply of power. The authors' figures for clearances for self-cooled units are minimum distances. We are pleased to note that Mr. Hughes advocates still greater distances, for in general it has been found that transformers are only allowed their bare floor-space and no breathing room. The question of the advantages of three single-phase transformers over a three-phase transformer and its comparison with a generator has already been dealt with. The period of time necessary for repairs of a core-type transformer as suggested by Mr. Hughes, viz. 24 hours, is rather short; the authors' experience is that three days is nearer the mark, and, after that, drying out is again necessary in most cases. The erroneous statement that shell-type coils are not in direct contact with the oil has been disposed of already, as also the question of sludge collecting in the oil ducts. Mr. Hughes is not correct in stating that coil supports as in Fig. 16 fail to compensate for the movement of coils at the moment of short-circuit. This device not only does not fail to compensate but it prevents movement of the coils under a sudden shock by the retardation of the dash pot. We agree that Figs. 13 and 14 and also Fig. 15 fail to compensate for movement since the springs are free to move instantaneously. The authors' opinion is that, as far as manufacturing conditions will allow, the ideal should be aimed at and that the magnetic centres of the cores should be as near in line as possible.

In reply to Mr. Wright, very rarely is trouble experienced by sludging in the cooling tubes on the tanks. The tubes can be cleaned if necessary by a long wire brush. The single-layer spiral winding is not the soundest job when the section of conductor is so small as to give a thin copper strip wound on edge which may cut through the insulation. Regarding magnetic shunts for high-reactance transformers, in the authors' patented construction (Fig. 25) the parasitic losses are reduced by about one-half compared with other constructions, so that the heating is certainly correspondingly reduced. Over one hundred such transformers are in operation and none have given any trouble.

Regarding Mr. Longman's vision of transport of the future, airships are hardly within the scope of this paper. The authors do not fear any possibility of deterioration of the iron at the maximum temperatures suggested. Transformers have been tested after years of service and the increase in iron loss has not been appreciably high. The case of a 1,250-k.v.a. three-phase core-type transformer 12 years old was investigated some time ago in which the increase in loss amounted to less than 10 per cent. Mr. Longman's experience of 50 per cent increase seems to the authors very abnormal, but might probably be explained by the breakdown of insulation of some of the core bolts or plates, thus providing short-circuits of high resistance and hence high losses. The authors have seen transformers, fitted with springs against short-circuits, destroyed due to sudden reaction on the spring, as stated earlier in the discussion. The suggestion that adjustments should be made top and bottom is not easily accomplished in practice, since the whole weight of the coils would have to be carried on the bottom springs. The authors think that a solid and firm foundation for the winding is the safest practice. The flux density varies considerably with the frequency, the iron loss required, and the rating. The magnetizing current should not exceed 6 per cent on a 600-k.v.a. transformer, while on a 7,800-k.v.a. transformer, as detailed in Table 2, it is less than 3 per cent.

Mr. Beard refers to road transportation, which is

thought by many to be a simple way out of railway-gauge limits. The authors do not entirely agree, and if the subject is closely studied they think such transportation will be found to be very costly, slow and unsafe. The bridge loading on many of the roads is very low and hence circuitous routes are necessary. For very short distances it is probably advantageous. The design of transformer tanks for outdoor service has not, up to now, been given much attention in this country, except for small pole- and platform-type transformers up to 200 k.v.a. For large units heavy boiler-iron tanks will be necessary, with heavy covers of castings or boiler plate with suitable watersheds. The terminals will have to be brought out through watertight glands in the cover or through overhanging pockets on the sides of the transformer. The question of price curves, Figs. 4*a* and 4*b*, has already been dealt with in reply to Mr. Watson (see page 580). With reference to Table 4, duplicate supplies have not been dealt with as this system of duplicate supply is not general practice. Building costs have not been considered, but these can easily be added by those desiring such information. Switchgear has not been referred to, since this paper deals with transformers rather than substation design, although the transformer cost is generally the determining factor of a substation. The paper is intended for general application and not for special undertakings, for all users do not stock a sufficient quantity of apparatus to warrant a general central stores. The authors regret that time will not permit of the compiling of the suggested tables, though they admit that these would be of valuable service. Regarding Fig. 7, the short-period overloads are proportionately greater for self-cooled apparatus than for artificially cooled. This is a large question and is bound up with the question of rating and temperature rise. We hope to revert to it at a later date. The authors state in the paper that the figures in Table 7 are given for a new transformer and one of reasonably good manufacture. Faulty work, bad service condition and rough handling on site will necessarily reduce these safety factors. The authors think that a large number of the transformer failures are attributed without proof to faults between turns, for often faults are so destructive as to destroy evidence. The fault may have been due to one of many causes, such as damage to coils in transit, moisture, developed faults due to faulty core, fracture of a welded joint, displacement of turns due to shock, etc. Mr. Beard's suggestion that adjustable reactances are inefficient may be correct, but their advantages over resistances are worth considering. Admitted that the power factor is reduced, though slightly, the power required to operate is less; also there is no break in the feeder circuit and hence no fear of loose contacts or overloading contacts, as would probably occur with a resistance. The resistance would be of enormous size and would probably have to be oil-immersed, and the capital cost would probably exceed the reactance cost. The control would not be so simple or so easy of manipulation. On the question of auto-transformers for interlinking we would direct Mr. Beard's attention to the qualifying statement in the paper (page 568): "The use of auto-transformers for interlinking systems of about equal voltages, though apparently attractive from the point of view of reduced capital cost, is not generally to be recommended." Reference to the magnetic shunts has already been made in the previous remarks. Mr. Beard's reference to increase in cost due to war conditions being greater for transformers than for other engineering apparatus is explained by the heavy increase in the price of copper, insulating materials (which were usually of Continental manufacture), the large percentage of labour in its manufacture, and the heavy increases in the cost of transformer oil.

We do not agree with Mr. Stedman's general assertion of the superiority of the core-type over shell-type transformers. Such a categorical statement cannot be made and, in this time-worn comparison, all the factors set out in the paper should be given consideration. Most of Mr. Stedman's other points have been dealt with above.

Mr. Stigant's interesting remarks on the effect of proportion of loss on maximum efficiency are a little beyond the point in question in the paper, for the authors state that the iron loss and copper loss should be *about* equal at $\frac{3}{4}$ load for maximum efficiency at this loading. If other proportions of loss are used a higher efficiency might be obtained, but the maximum efficiency of any transformer characteristic is when the losses are approximately equal. His further statements *re* proportion of losses for high overloads agree with the authors' remarks in the paper. Mr. Stigant appears to forget that overhead lines are subject to atmospheric disturbances, which are in the main more severe than any switching surges, and this is the main reason for distinction between overhead and cable connections to transformer terminals. The percentage values of the windings recommended for reinforcement are based on experience, and the probable distance of travel of high-frequency surge-voltages into the windings. The definition of reinforced turns, as understood by the authors, is that percentage of the winding which has the insulation of its individual turns increased over and above that of the remainder of the winding. A winding may be said to be reinforced when the insulation between turns exceeds that necessary for test conditions and normal safety. A modern transformer may be said, in a way, to be reinforced throughout its windings, since the insulation between turns exceeds many times that of normal requirement, while the end turns within the percentages stated are further reinforced for the abnormal voltage rises. Mr. Stigant's exposition of the theory of transient waves is interesting. The value of the amplitude cannot in any case exceed that due to atmospheric disturbances. The care necessary in insulating tappings and blank ends is appreciated by the authors, who have followed this practice for some long time past.

With reference to Mr. Clothier's remarks, the authors regret that acknowledgement of the assistance of the Newcastle Electric Supply Company was inadvertently omitted in the advance copies of the Paper, but this has been rectified in the *Journal*. The North-East Coast system has undoubtedly proved a very valuable ground for experience in transformer engineering, but

we do not feel called upon to modify the remarks in the opening paragraphs of the paper. Up to a few years ago, the largest transformer in this country was only of 2,000 k.v.a. capacity and the maximum voltage only 20,000 volts. When this is compared with the large sizes and voltages dealt with in the paper and already coming rapidly into use, we think our remarks are, to a certain extent, justified. Certain manufacturers have gained more extensive experience in apparatus for foreign markets, and are in a position to tackle any problems involved in the new schemes for power supply, provided they get the necessary assistance and co-operation from those responsible for specifying and ordering the plant.

# MAGNETIC STORMS.

By C. CHREE, Sc.D., LL.D., F.R.S.

(*Lecture delivered before* THE INSTITUTION, 1 *May*, 1919.)

**1.** The term magnetic storm is usually confined to large disturbances, but no satisfactory classification can be based on mere size. A disturbance that would be very ordinary if experienced in high latitudes may be outstanding near the magnetic equator. Also, as we shall see presently, synchronously with small disturbances in one part of the world we may have large disturbances in another. Thus our classification of disturbances, if based on size, would be largely dependent on where we happened to have records from. In the present paper the term "magnetic storm" is taken to include all magnetic disturbances not due to human agency.

Members of an Institution devoted to applied science, before taking an interest in magnetic storms, may wish to know whether the subject is of any immediate practical importance. Is there any class of the community to whom it would be an advantage to know when a storm has occurred in the past, or when it is likely to occur in the future? I hope to show that magnetic storms are events of some practical importance, but their chief interest, at least at present, lies much more in the domain of pure than in that of applied science. Our knowledge of magnetic storms is still scanty, considering that magnetographs came into operation more than 60 years ago. Some of the reasons for this slow advance of knowledge are not far to seek. The general public—and in this country Government in scientific matters has not hitherto been in advance of public opinion—thinks that all that requires to be done is the erection of a few observatories and the publication of a summary of observational results. A staff is considered adequate if it can keep the instruments running and prepare results for publication according to a fixed programme. The members of the staff may be punctilious in the discharge of their routine duties, the observational data may be accurate and publication may be prompt, and yet there may be little, if any, increase of real knowledge. The turning out of heaps of excellent bricks is not the same thing as the construction of a fine house. One thing that has militated against an increase of knowledge is that as a rule the staff of an observatory knows little about any records except its own. In some countries several observatories have been under the control of a central institution, e.g. the Coast and Geodetic Survey of the United States, or the Survey Department of India. In such a case if there is some educated intelligence in control at the central office, with a taste for research and adequate leisure, a good deal may be learned without going outside the material obtained by the single institution. In this country prior to 1908 there were no two observatories running magnetographs which were under a common control. Greenwich is under the Admiralty. Stonyhurst belongs to the Jesuit Fathers. Falmouth—now extinct as a magnetic observatory—belonged to the Royal Cornwall Polytechnic Society. During my own time, Kew Observatory has been successively under the control of the Royal Society's Kew Committee, the National Physical Laboratory, and the Meteorological Office. Under these circumstances it is perhaps not surprising that the comparative study of magnetic storms at different parts of the United Kingdom is still in its infancy. One of the objects of this paper is to throw some fresh light on this subject.

The United Kingdom forms a very small fraction of the earth's surface, and a study confined to it could hardly do more than touch the fringe of the subject. The second and principal object of the paper is to give a brief account of synchronous phenomena observed at stations in widely different parts of the earth.

More than five years have elapsed since I was charged with the discussion of the magnetic records obtained in 1911 and 1912 by the second Antarctic Expedition led by Captain Scott. The expedition ended fatally for its leader, but so far as the magnetic work was concerned it was eminently successful. The physical observers, Dr. G. C. Simpson, F.R.S., and Mr. C. S. Wright, obtained nearly continuous magnetic records for 22 successive months. These included many magnetic storms. A number of these were selected

and a successful appeal was issued to certain representative observatories for copies of the records obtained of these disturbances. Some of the comparative results obtained will be described in the present paper.

The most convenient order of presenting the subject will be, I think, to deal first with some data confined to the United Kingdom, and later with synchronous data from a variety of stations.

**2.** As the outcome of a conference with representatives of the Institution of Mining Engineers, a little over a year ago, the Director of the Meteorological Office agreed to provide week by week information about the magnetic declination at Kew Observatory. Data for the week ending on a Saturday are supplied by Wednesday of the week following to the Institution of Mining Engineers and the editors of certain journals who undertake to publish them. Mean values are given for the twelve 2-hour periods 0h to 2h, 2h to 4h, and so on throughout each day. These values are given to the nearest 0'·5. A "character" figure 0, 1 or 2 is ascribed to each day. "0" means a day wholly free from any but small disturbances, "1" a day part or all of which is moderately or considerably disturbed, "2" a day part or all of which is highly disturbed. The following is the official explanation of these terms. "The normal value for an hour is the mean declination for that hour in the month, derived from quiet days only, or from all days excluding those of 'character' 2. On a day of 'character' 0 declination at any hour will usually be within about 3′ of the normal. On a day of 'character' 1 the departure from the normal will usually not exceed 5′, but it may occasionally be as much as 10′ or even more. On a day of 'character' 2 the departure from the normal will seldom exceed 20′, but departures of 30′ or even in extreme occasions of 1° or more may occur." Any 2-hour interval which is very highly disturbed has an * assigned to it, and the attached footnote states "large disturbance during this interval." In assigning these asterisks it is difficult to follow an absolutely rigid rule, but the guiding principle is that the disturbance during the two hours in question is part of a disturbance with a range of at least 20′. The asterisk is intended as a warning that the value affected cannot claim any high precision, and that any observation taken at the time had better be scrapped unless a low level of accuracy suffices. Ascribing "character" figures has been part of an international scheme since 1906, but in the international scheme all the magnetic elements are considered, and horizontal force is at many places the most disturbed element. Thus the results obtained during the past year at Kew have an exceptionally direct bearing on the problem which concerns surveyors. Due allowance must of course be made for the fact that the results of a single year may depart a good deal from the average, and undoubtedly the year as a whole has been more than usually disturbed, especially during December 1918.

Of the 365 days from 17th March, 1918, to 16th March, 1919, inclusive, 154 or 42 per cent got character 0, 138 or 38 per cent got character 1, and 73 or 20 per cent got character 2. On the character 0 days, if Kew was fairly representative of the country, there was no 2-hour period the mean value of which was likely to be affected by disturbance by more than 3′. But on the other days, 58 per cent of the whole, disturbance effects as large or larger than this might be expected during at least part of the day. Even on days of character 2 there are usually intervals, generally in fact considerable intervals, during which the departure from the normal value is small. The danger, moreover, of getting a very abnormal value may always be reduced by taking a mean from a number of observations extending over a considerable time. Still no observation taken on a day of character 2 should be accepted without special consideration.

The distribution of days of character 2 throughout the year was irregular. During the 17 weeks commencing with 19th May and ending with 14th September, 1918, only nine days got character 2, while the 17 weeks beginning on 10th November, 1918, and ending on 8th March, 1919, contained 36 such days. Midsummer is usually a quiet season, while February and March show more than usual disturbance. Thus the phenomena were so far not abnormal. December, however, is usually one of the quietest months. Thus the occurrence of five days of character 2 in the single week 8th to 14th December was certainly abnormal.

**3.** The international scheme takes no notice of individual hours of the day. Some information was, however, given in my Kelvin Lecture * as to the incidence of disturbance throughout the 24 hours at Eskdalemuir. It was shown that disturbance was much more frequent between 15 h (3 p.m.) and 3h than during the remaining 12 hours of the day. This result, however, was dependent on the two horizontal components of magnetic force. The declination data obtained during the past year add materially to our knowledge of the subject. The number of 2-hour periods starred as highly disturbed was as follows :—

| Interval .. .. .. | 0–2h | 2–4h | 4–6h | 6–8h | 8–10h | 10–12h | 12–14h | 14–16h | 16–18h | 18–20h | 20–22h | 22–24h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of days disturbed | 27 | 22 | 11 | 4 | 1 | 1 | 3 | 11 | 25 | 45 | 47 | 39 |

Thus of the 236 highly disturbed 2-hour intervals, the twelve hours 4h to 16h contributed only 31, or little over 13 per cent. The interval 20h-22h was highly disturbed in one day out of eight, while a highly disturbed time between 8h and 10h or between 10h and 12h occurred on only one day in the year. A single year may present considerable anomalies, but it is obvious from the above figures that declination observations taken between 4 p.m. and 4 a.m. are much more likely to suffer seriously from magnetic storms than those taken between 4 a.m. and 4 p.m. This seems a result of some practical importance, because the smallness of the regular diurnal changes and the reduction of artificial disturbances at night have encouraged mining engineers to consider the night hours to be specially favourable for observations of high precision. It does not of course follow that night

* *Journal I.E.E.*, 1916, vol. 54, p. 418, Figs. 10 and 11.

observations should cease, but in their case it is specially desirable to consult a magnetic observatory as to the presence or absence of a magnetic storm.

A possibility that will naturally have suggested itself is that the cry of "wolf" based on Kew curves alone may not be justified when the English and Welsh, and still more when the Scottish coalfields are concerned. The facts, however, as will presently appear, are rather the other way. The really doubtful thing is whether conclusions based on Kew alone are not too optimistic when applied to the coalfields.

The proximity of Kew and Greenwich renders it unlikely that inter-comparison of the curves of these two places will throw much light on the variability of declination disturbance throughout England. Fortunately, while the control of Falmouth Observatory lay with the Royal Cornwall Polytechnic Society, the practice there was to apply to Kew Observatory for advice on magnetic matters, and this naturally led to the frequent presence of Falmouth curves at Kew. Magnetic registration ceased at Falmouth in 1913, and all the old magnetic curves were subsequently transferred to the custody of Kew Observatory. Thus every facility now exists there for a magnetic comparison of Kew and Falmouth. The resemblance of the Kew and Falmouth curves even in minute details is usually very close, and I feel tolerably certain that the magnetic character of the day for any place in the south of England can be inferred satisfactorily from a study of the Kew curves alone. At the same time, no minute comparison had been made up to now of the relative amplitudes of corresponding *irregular* declination changes at Kew and Falmouth, and any differences that might exist tended to be obscured by the great difference between the scale values of the declination curves. The equivalent of 1 mm. of ordinate was 1′·17 at Falmouth as against only 0′·87 at Kew.

**4.** Eskdalemuir has throughout been under the same control as Kew, and it may appear strange that up to now no systematic minute comparison had been made of declination curves from the two observatories. This is mainly due to the fact that declination was recorded at Eskdalemuir only for a short time. When the magnetographs were first run in 1908, D and H (declination and horizontal force) were recorded as at Kew, but the underground magnetic chamber proved so damp that there were frequent interruptions of the trace, and before regular registration was introduced it was decided on the advice of the Gassiot Committee to record N and W (North and West components of force) instead of H and D. There is usually a considerable resemblance between W and D curves, but the difference precludes any rapid deduction of exact D values from W and N curves. The publication of D data for mining engineers brought the comparison of Kew and Eskdalemuir data to the front, and has been mainly responsible for the comparison recently made. The only previous comparison of the kind, so far as I know, is one made fully 50 years ago between Stonyhurst and Kew, by the Rev. W. Sidgreaves, S.J., then as now * in charge of Stonyhurst Observatory, and Dr. Balfour Stewart, then Superintendent at Kew. Their paper * is described as a "preliminary comparison," so presumably a more elaborate comparison had been contemplated. It compared the size of large rapid changes of D at the two observatories. Thirty-seven changes occurring in 14 days between January and May 1868 were measured, the curves showing the changes being reproduced. In the case of the slower movements the amplitudes at the two stations were found to be practically equal, but in the case of the more rapid movements the amplitude at Stonyhurst exceeded that at Kew, the excess being greater the more rapid the change. Including every case we get (sum of 37 movements at Stonyhurst) ÷(sum of 37 movements at Kew) = 1·20. The excess at Stonyhurst was really underestimated owing to a misunderstanding. The scale values of the instruments were supposed to be equal, whereas the D magnetograph at Kew is a good deal more sensitive than later instruments of the same make. Thus while 1 mm. of ordinate represents only 0′·87 at Kew it has represented 1′·17 at Falmouth, 1′·13 at Stonyhurst, and 1′·12 at Eskdalemuir. Allowing for this, we deduce from Sidgreaves' and Stewart's comparison that the Stonyhurst amplitude was about 1·3 times that at Kew for the slowest changes and about 1·56 times as great for the average change.

Satisfactory Eskdalemuir D curves were available for only a few winter months of 1908 and 1909. Taking these and the corresponding Kew curves, a number of turning points were selected, and the amplitudes of the changes between the successive turning points were measured. Many of the movements were purely oscillatory, the movement between successive turning points being throughout in one direction and the rate of change fairly uniform. But in other cases the movement, though on the whole in one direction, was interrupted by minor short-period oscillations, and the rate of change was often far from uniform. A good many so-called "bay" movements were included. These represent a deflection from the normal which gradually increases to a maximum and then subsides, so that the disturbed curve is all on one side of the normal. If time had permitted, it would have been better to treat the different types of movement separately, but too ambitious a programme may defeat its own object.

After dealing with the Eskdalemuir and Kew movements, I measured all the corresponding Falmouth curves as far as possible. Unfortunately, during 1908–9 the Falmouth curves suffered somewhat from movements of iron in the observatory, and satisfactory measurements were impracticable in a few cases. At this stage the old comparison with Stonyhurst was discovered, and Father Sidgreaves, on being applied to, kindly lent a number of Stonyhurst curves representing summer as well as winter. This enabled winter records to be compared for all 4 observatories, and summer records for Stonyhurst, Falmouth and Kew. In general the resemblance between the movements at the different stations was very close. This is clear on inspection of Figs. 1 and 2. Corresponding turning

* Since this was written the Reverend W. Sidgreaves has died.

* *Proceedings of the Royal Society*, vol. 17, p. 236.

points at the different observatories are denoted by the same letters. To avoid overcrowding, the Stonyhurst records are not included. The movements there invariably occupied an intermediate position between the movements at Kew and at Eskdalemuir. Fig. 1 approximately covers the interval 19h 40m on 18th October to 8h 50m on 19th October, 1909. Fig. 2 includes two intervals, one of about $5\frac{1}{3}$ hours commencing a little after 15h on 23rd October, 1909, the other of about $5\frac{2}{3}$ hours commencing near 22h 40m on 29th January of the same year. Before dealing with particular points illustrated by the curves, it will be convenient to consider the general results of the comparison.

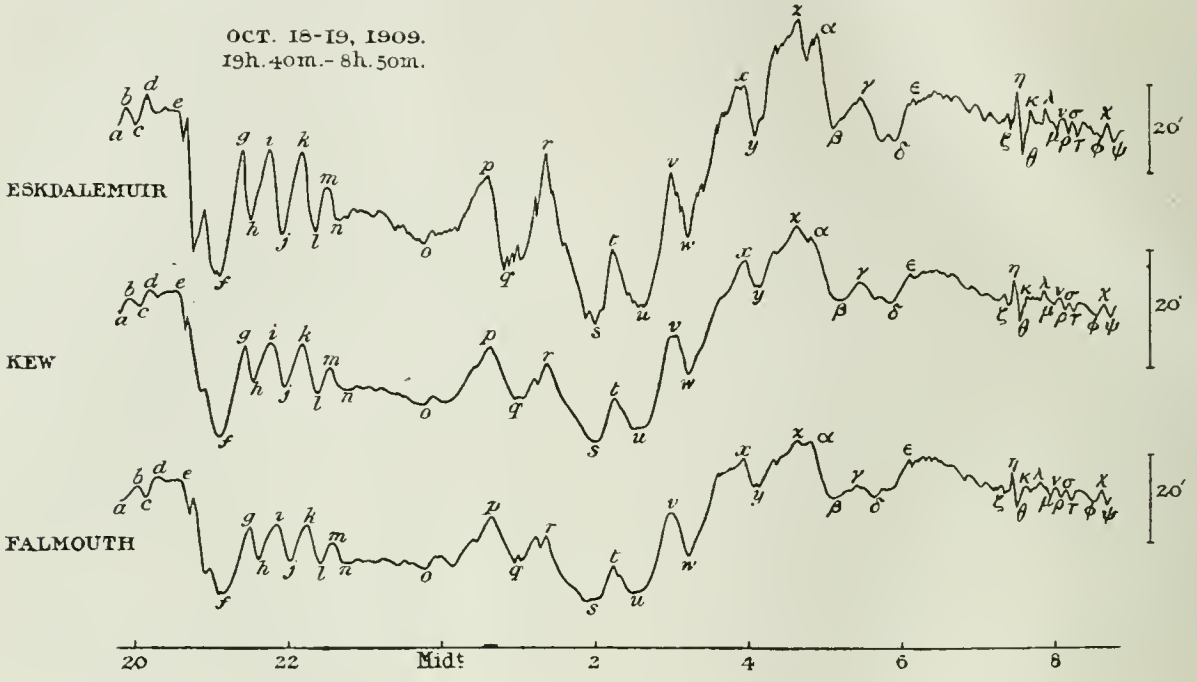



FIG. 1.

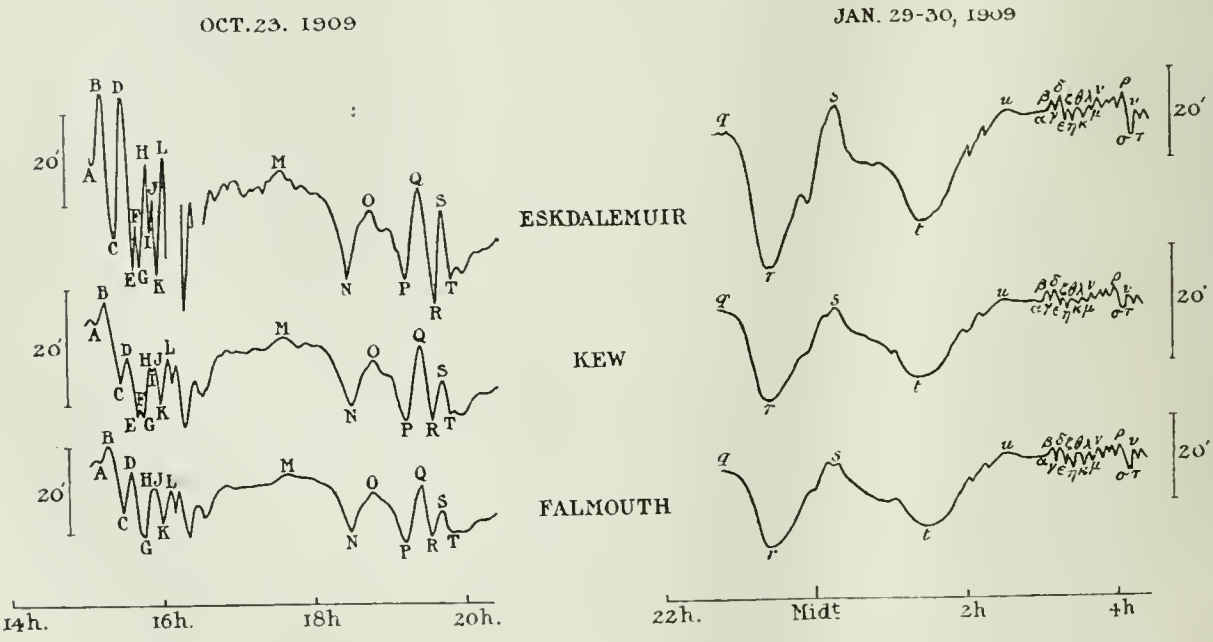



FIG. 2.

**5.** Table 1 deals separately with the observations of each month. It gives the number of movements

measured, and the ratios borne by the sum of the movements at Falmouth, Stonyhurst and Eskdalemuir to the corresponding sum at Kew. The first three pairs of columns include all the movements. The last three are confined to those cases in which the rate of movement as measured at Kew exceeded 0″·5 per minute. The rates were derived from the amplitudes and durations, the former being measured to the nearest 0″·1, the latter to the nearest minute. At Stonyhurst and Eskdalemuir the ratio to the movement at Kew is in most months for the faster movements above the average, but the excess is less decisive than in the comparison made by Sidgreaves and Stewart. There were, moreover, a good many exceptions to the general rule. It would obviously have been fairer to consider the rate of change at both the stations compared. If this were done, the tendency for the ratio of the Stonyhurst or Eskdalemuir movement to the Kew movement to increase with the rate would probably be more decided.

In the case of Kew and Falmouth, the influence of rate is certainly small. It was gone into carefully. Rates were calculated to 0″·01 per minute, and the observations were grouped according to the rates, nine groups being formed. The comparisons were limited to the eight months October, November and December 1908, and January, February, October, November and December 1909, so that no summer data were included. The results were as follows, the rates of change per minute being as stated :—

| Rate per minute .. | 0″·0–0″·1 | 0″·1–0″·2 | 0″·2–0″·3 | 0″·3–0″·4 | 0″·4–0″·5 | 0″·5–0″·6 | 0″·6–0″·8 | 0″·8–1″·0 | >1″·0 |
|---|---|---|---|---|---|---|---|---|---|
| Number of cases .. | 76 | 132 | 64 | 52 | 30 | 18 | 20 | 13 | 11 |
| Mean amplitude .. | 2″·44 | 3″·82 | 4″·89 | 6″·02 | 6″·88 | 6″·72 | 6″·38 | 6″·59 | 8″·21 |
| Falmouth Movement / Kew Movement .. | 1·30 | 1·22 | 1·20 | 1·24 | 1·20 | 1·24 | 1·10 | 1·13 | 1·19 |

The mean value of the ratio Falmouth/Kew from all the observations of the eight months was 1·21, the mean size of the movement being 4″·68. On the whole, as in Table 1, there is if anything a reduction in the ratio with increase of rate. The rapid rates were, however, comparatively few, and the very slow rates answered mainly to small movements, which could not be measured to the same relative accuracy as the larger ones. Thus the result is somewhat doubtful.

**6.** A factor of possible significance is the influence of size on the ratio. This might be important, in view of the comparatively small average amplitude of the changes having rates less than 0″·3 per minute. In view of this possibility, a group was formed of cases common to Falmouth, Eskdalemuir and Kew, which

TABLE 1.

*Comparison of Irregular Declination Changes at British Observatories.*

| Date | All Movements | | | | | | Movements faster than 0″·5 per Minute at Kew | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Falmouth and Kew | | Stonyhurst and Kew | | Eskdalemuir and Kew | | Falmouth and Kew | | Stonyhurst and Kew | | Eskdalemuir and Kew | |
| | Cases | F./K. | Cases | S./K. | Cases | E./K. | Cases | F./K. | Cases | S./K. | Cases | E./K. |
| 1908 | | | | | | | | | | | | |
| October .. | 23 | 1·27 | 15 | 1·93 | 23 | 2·33 | 3 | 1·22 | 2 | 2·01 | 5 | 2·46 |
| November .. | 92 | 1·23 | 42 | 1·86 | 98 | 2·20 | 9 | 1·24 | 8 | 2·08 | 11 | 2·85 |
| December .. | 20 | 1·24 | — | — | 20 | 2·09 | — | — | — | — | — | — |
| 1909 | | | | | | | | | | | | |
| January .. | 56 | 1·21 | 56 | 1·65 | 57 | 2·05 | 14 | 1·22 | 10 | 1·81 | 11 | 2·38 |
| February .. | 44 | 1·18 | 25 | 1·60 | 44 | 1·94 | 8 | 1·19 | 5 | 1·88 | 8 | 2·07 |
| March .. | 103 | 0·99 | 109 | 1·62 | — | — | 36 | 1·00 | 36 | 1·75 | — | — |
| April.. .. | 18 | 0·98 | 18 | 1·31 | — | — | 3 | 1·04 | 3 | 1·39 | — | — |
| May .. .. | 33 | 1·01 | 33 | 1·45 | — | — | 17 | 1·04 | 17 | 1·44 | — | — |
| June .. | 25 | 1·08 | 25 | 1·50 | — | — | — | — | — | — | — | — |
| July .. .. | 11 | 1·20 | 11 | 1·61 | — | — | — | — | — | — | — | — |
| August .. | 49 | 1·10 | 49 | 1·51 | — | — | — | — | — | — | — | — |
| September .. | 44 | 1·15 | 44 | 1·83 | — | — | 14 | 1·14 | 14 | 2·14 | — | — |
| October .. | 80 | 1·11 | 69 | 1·78 | 87 | 2·24 | 22 | 1·08 | 25 | 1·90 | 26 | 2·45 |
| November .. | 31 | 1·19 | — | — | 31 | 1·83 | 1 | 1·16 | — | — | — | — |
| December .. | 70 | 1·35 | 37 | 2·10 | 73 | 2·22 | 4 | 1·37 | 2 | 1·98 | 4 | 2·17 |
| All months | 699 | 1·14 | 533 | 1·68 | 433 | 2·14 | 131 | 1·09 | 122 | 1·79 | 65 | 2·44 |

had a range at Kew greater than 10′. These cases numbered 36, the mean amplitude observed at Kew being 14′·0. The ratios borne to this mean by the corresponding Falmouth and Eskdalemuir means were respectively 1′·16 and 2′·02. Comparing these with the mean results in Table 1, we infer that mere size has little, if any, influence on the ratio. Again, taking the winter months of 1908, the 33 cases in which the duration of movement exceeded 30 minutes were grouped together. For this group the mean range at Kew was 4′·6, and the ratios borne to this by the corresponding Falmouth and Eskdalemuir mean ranges were respectively 1·20 and 1·92. In the case of Falmouth this last investigation was extended to the winter months of 1909. The mean range at Kew for this group was 7′·3 and the corresponding Falmouth range was greater in the ratio of 1·21 : 1. These investigations suggest that neither the absolute magnitude nor the duration of the movement is of much importance. But, as we have already seen, with increase of rate there is a tendency for the northern stations to show an enhanced relative amplitude. The monthly values in Table 1 also suggest that the amplitude at Kew relative to the amplitudes at the other stations is distinctly greater in summer than in winter. Several years' results, however, would be necessary to put such a conclusion adequately to the test.

**7.** To arrive at a clearer idea of the variability in the ratio borne by the Falmouth to the Kew changes, the observations of the winter months of 1908 and 1909 were arranged in 63 groups, and a value of the ratio was found for each group. Most groups represented the cases of a single day. Sometimes, however, when a succession of movements occurred near midnight, two days contributed to a group, and when there was a considerable quiet interlude in a day, the earlier and later movements formed separate groups. The value of (Falmouth range)÷(Kew range) being 1·21 for all the groups combined, the individual values given by 39 of the groups lay between 1·11 and 1·31. Only two values fell short of 1·01 and only six exceeded 1·41, the extreme values being respectively 0·97 and 1·58.

Every single one of the 433 movements measured at Eskdalemuir exceeded the corresponding Kew movement, and the same was true of the 533 movements measured at Stonyhurst, with one exception. On the other hand, in a few cases, movements that attained a considerable size at Eskdalemuir and Stonyhurst were but feebly represented at Falmouth and Kew. A good illustration of this is afforded by a series of movements between 15h and 16h on 23rd October, 1909, shown in Fig. 2. The amplitudes of these successive movements were :—

| Number . . | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| At Kew . . | 4′·1 | 14′·0 | 4′·0 | 10′·0 | 1′·2 | 8′·2 | 1′·1 | 1′·0 | 5′·6 |
| At Stonyhurst . . | 9′·7 | 23′·1 | 16′·5 | 27′·7 | 3′·2 | 17′·4 | 7′·9 | 2′·5 | 12′·7 |
| At Eskdalemuir . . | 16′·2 | 32′·3 | 31′·9 | 39′·2 | 10′·1 | 23′·5 | 16′·2 | 7′·8 | 17′·4 |

The movements were alternately to west (up the sheet) and to east, but the third westerly movement (E F in Fig 2) is omitted. Relatively considered, the Kew movements are all smaller than usual, but this is much more the case with the first two westerly than with the first two easterly movements. The smallness of the movements numbered 5 and 8 is shared by Stonyhurst. On the same occasion after a comparatively quiet interlude, oscillations were resumed about 18h. These later oscillations at Kew were quite as large as usual relative to the Stonyhurst and Eskdalemuir movements.

On the other hand 18–19th October, 1909 (see Fig. 1), affords a remarkable illustration of a complete change in the type and period of oscillation without any notable change in the relative magnitude. If we put the movements prior to 6h on 19th October into one group and those subsequent to 7h into another, we obtain the following mean values :—

| | Duration | Range at Kew | (Eskdalemuir range) ÷ (Kew range) |
|---|---|---|---|
| Earlier 27 movements | 19 min. | 8′·1 | 2·16 |
| Later 10 movements | 5 min. | 2′·5 | 2·36 |

Even more striking, perhaps, is the example afforded by the movements of 29–30th January, 1909 (see Fig. 2). We have here two large "bays," followed after an interval of about 40 minutes by a series of rapid oscillations. The "bays" are composed of 4 principal movements, east, west, east, west, their mean duration being 57 minutes. The movements averaged 29′·9 at Eskdalemuir, and 14′·25 at Kew, the ratio of the movements at the two places thus being 2·1 : 1. Measurements made of 13 of the later rapid movements, with an average duration of 3·0 minutes, gave for the average size 3′·15 at Eskdalemuir and 1′·49 at Kew, the ratio being again 2·1 : 1.

In forming any visual estimate in Figs. 1 and 2, the difference in the scale values at the three observatories must be remembered. In angular measure 1 mm. of ordinate in a Kew curve is equivalent to only 0·74 mm. in a Falmouth curve and to 0·78 mm. in an Eskdalemuir curve. It must also be remembered that the disturbing force required to produce a change $\Delta D$ in declination is $H \Delta D$, where H is the local value of horizontal force. In 1909 the mean values of H at the four observatories were 10835γ at Eskdalemuir, 17424γ at Stonyhurst, 18506γ at Kew, and 18802γ at Falmouth. Thus the disturbing forces required to produce declination changes of 1′ were respectively 4·90γ, 5·07γ, 5·38γ and 5·47γ. If instead of angular displacements, we compared the force equivalents, we should have in the last line of Table 1, 1·16 for 1·14 in the case of Falmouth and Kew, 1·58 for 1·68 in the case of Stonyhurst and Kew, and 1·95 for 2·14 in the case of Eskdalemuir and Kew.

**8.** It is desirable to know whether the increase in range relative to Kew shown by *irregular* movements at Eskdalemuir, Stonyhurst and Falmouth obeys any

regular law. If we confine ourselves to the winter months, for which alone Eskdalemuir results are available, we have the three relations: (Eskdalemuir range) ÷ (Kew range) = 2·14, (Stonyhurst range) ÷ (Kew range) = 1·79, and (Falmouth range) ÷ (Kew range) = 1·21. Relative to Kew, the north latitude and west longitude of the other three stations are :—

| | |
|---|---|
| Eskdalemuir .. .. | +3°·9 N, +2°·9 W |
| Stonyhurst .. .. | +2°·4 N, +2°·2 W |
| Falmouth .. .. | −1°·3 N, +4°·8 W |

It will be found that the relations we have established between the ranges are all approximately in harmony with the equation

$$\text{Range} = (\text{Range at Kew})\{1 + 0{\cdot}23\Delta\lambda + 0{\cdot}10\Delta l\} \quad . \quad (1)$$

where $\Delta\lambda$ and $\Delta l$ are the north latitude and west longitude relative to Kew measured in degrees.

ere long direct evidence on this point may be forthcoming.

**9.** Of all forms of magnetic disturbance the S.C. (sudden commencement) has probably attracted most attention. It derives its name from the fact that many large storms are preceded by S.C.'s. If we take a station like Alibag (Bombay) in low latitudes the changes in the D and V (vertical force) curves during an S.C. are insignificant, while H increases rapidly for several minutes. The phenomena at Helwan (Egypt) are very similar to those at Alibag. When we come as far north as Kew the pre-eminence of the H movement diminishes. The principal feature is still the rise in H, but it is sometimes preceded by a small rapid fall. At Eskdalemuir the oscillatory tendency is more prominent. Some six S.C.'s were recognized in the Antarctic curves of 1902–3, and at least thirteen in the Antarctic curves of 1911–12. The Antarctic movement was invariably oscillatory. A curious

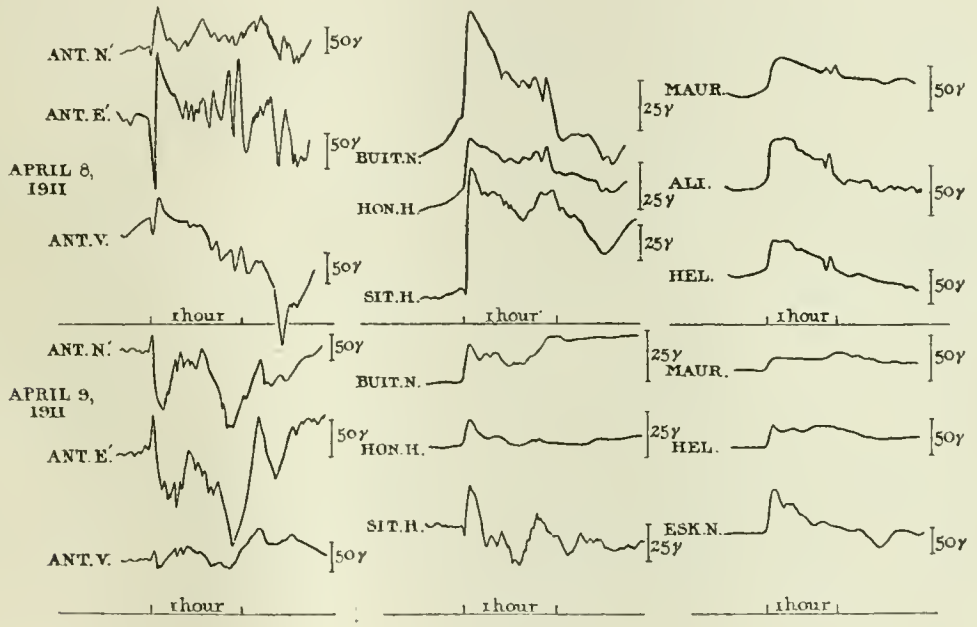



FIG. 3.

If on the other hand we take the summer months, we find from the Kew, Falmouth and Stonyhurst ranges :—

$$\text{Range} = (\text{Range at Kew})\{1 + 0{\cdot}19\Delta\lambda + 0{\cdot}06\Delta l\} \quad . \quad (2)$$

The application of either formula to the country at large is necessarily speculative. There can, however, be but little doubt that at least in 1908 and 1909 the size of irregular D movements throughout England increased something like 20 per cent for an increase of 1° in latitude. If formula (1) were applicable throughout the whole of the United Kingdom, irregular D changes at Unst in the Shetlands and Lewis in the Hebrides would be fully thrice as great, and those in the extreme north-west of Ireland 2½ times as great, as at Kew. It is perhaps not too much to hope that

diversity of type appears, however, in the Antarctic, which is illustrated by the S.C.'s on two successive days, 8th April and 9th April, 1911, which are reproduced in Fig. 3. The Antarctic magnetographs recorded V as usual, but instead of H and D they recorded two rectangular components of force designated N′ and E′. Their directions were respectively 7°·6 east of north and 7°·6 south of east.

It had been intended to record N and E, the true north and east components, but the instruments were in an ice cave where astronomical observations were difficult, and a mistake was made in the original orientation. Movement up the sheet means in N′ a force in a nearly northerly direction, in E′ a force nearly easterly, and in V a force urging the north pole of a magnet towards the earth's centre (in other words a numerical decrease in vertical force, as the south pole

dipped). The position of the Antarctic station was 77° 38′ S lat., 166° 24′ E long.

There are three panels in Fig. 3. The upper part of each refers to 8th April, the lower part to 9th April. The first panel relates to the Antarctic. It will be observed that on 8th April the first Antarctic S.C. movement is down the sheet in all three elements, whereas on 9th April it is up the sheet. In the second panel the upmost curve in both cases belongs to Buitenzorg (6° 35′ S, 106° 49′ E), the middle curve to Honolulu (21° 19′ N, 158° 4′ W) and the lowest curve to Sitka (57° 3′ N, 135° 20′ W). The element recorded is N at Buitenzorg, and H at Honolulu and Sitka. The time scale * at these three stations and the Antarctic is practically 20 mm. to the hour. Sitka differs from Buitenzorg and Honolulu in showing a differed in sensitiveness, that at Alibag being the most sensitive and that at Eskdalemuir the least. In every case in the third panel the S.C. movement appears to be unidirectional, though this is rather exceptional for Eskdalemuir.

**10.** It will be noticed that about an hour after the S.C. on 8th April the curves from all the stations outside the Antarctic contain a sharp movement down the sheet, something like an S.C. movement reversed. It seems to have occurred simultaneously at all the stations. A similar phenomenon was observed in H and N curves after a considerable proportion of the S.C.'s recorded in 1911 and 1912. Fig. 4 shows the form it took on three occasions. The upper panel refers to 19th August, 1911, when the "crest" or elevated portion between the prominent upward and

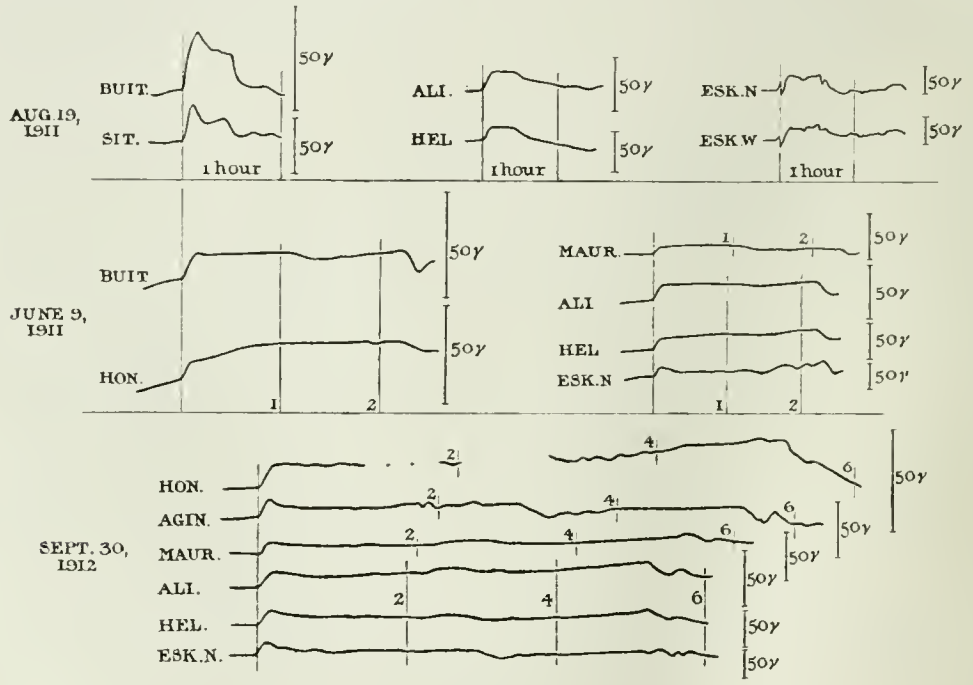



Fig. 4.

small rapid fall preliminary to the large rise, but there is no difference in type between the two days at any one of the three stations. The sensitiveness varied greatly, the Buitenzorg magnetograph being the most sensitive. The excess of the Sitka movement was thus greater than it looks.

The third panel in Fig. 3 shows the changes in H at Mauritius (20° 6′ S, 57° 33′ E), Alibag (18° 39′ N, 72° 52′ E) and Helwan (29° 52′ N, 31° 21′ E) on 8th April, and the changes in H at Mauritius and Helwan and in N at Eskdalemuir (55° 19′ N, 3° 12′ W) on 9th April. The magnetographs at these four stations are of the Kew pattern, in which the time scale is usually about 15 mm. to the hour, but the time scale at Mauritius is appreciably more open than this. The instruments

* Numerical particulars as to scale values here and elsewhere in the paper refer to the original curves. In the paper the curves are reduced, the reduction being different in different figures, but uniform for all the curves in any one figure.

downward movements was very short. The central panel refers to 9th June, 1911, when the crest lasted fully 2 hours, and the lower panel to 30th September, 1912, when the crest lasted fully 5 hours. The curves for 19th August, 1911, include the Buitenzorg N and Sitka H curves from Eschenhagen pattern instruments, the Alibag and Helwan H curves—as usual very similar—from Kew pattern instruments, and the N and W (west component) curves from Eskdalemuir. The latter show the crest imperfectly. Their chief interest is that the S.C. movement exhibits a remarkable oscillation, not visible at the other stations.

The curves for 9th June, 1911, include the Buitenzorg N and Honolulu H curves from Eschenhagen instruments, the Mauritius, Alibag and Helwan H curves, and the Eskdalemuir N curve. At most of the stations, especially at Honolulu, the crested part

slopes up the sheet, showing a gradual rise in H or N, possibly from a separate cause.

The curves for 30th September, 1912, show H changes at Honolulu, Agincourt (43° 47′ N, 79° 16′ W), Mauritius, Alibag and Helwan, and N changes at Eskdalemuir. The Honolulu curves were partly interrupted by scale value determinations. The differences in the apparent length of the crest arise from differences in the time scales. The Agincourt time scale is a good deal more open than that of the usual Kew pattern. The decided movement down the sheet terminating the crest appeared to be simultaneous at all the stations.

The phenomenon of the crest seems to be especially regular at Alibag, the only station so far as I know where it has previously been observed. Dr. Moos in his elaborate discussion of Bombay magnetic observations gives a number of examples, some more prominent than any in Fig. 4. Dr. Moos suggested a seismic origin, but seemed unable to make up his mind on the point. The phenomenon merits careful study. It is obviously not a local one, and I see no special reason for associating it with mechanical strains and stresses in the earth's interior. It recalls a suggestion made by Professors Birkeland and Störmer to account for aurora in lower latitudes. Aurora and associated magnetic storms are, according to these investigators, due to electrical ions or corpuscles from the sun. The considerable distance from the magnetic poles at which aurora is often seen is a difficulty. The suggestion was that somehow the earth got possessed at the com-

TABLE 2.

*Particulars of "Sudden Commencements" at Antarctic Station.*

| Date | Hour | First Phase | | | Second Phase | | |
|---|---|---|---|---|---|---|---|
| | | $\bar{H}$ | $\psi$ | $\chi$ | $\bar{H}$ | $\psi$ | $\chi$ |
| *Class I* | h m | γ | o | o | γ | o | o |
| 8 May, 1902 .. .. .. | 11 59 | — | — | — | — | — | — |
| 6 November, 1902 .. .. .. | 15 52 | — | — | — | — | — | — |
| 13 December, 1902 .. .. .. | 12 29 | — | — | — | — | — | — |
| 8 April, 1911 .. .. .. | 11 21 | 111 | 269 | 12*a* | 227 | 72 | 16*b* |
| 29 May, 1911 .. .. .. | 14 34 | 27 | 216 | 14*a* | 62 | 54 | 23*b* |
| 9 June, 1911 .. .. .. | 16 31 | 18 | 234 | 14*a* | 24 | 59 | 16*b* |
| 19 August, 1911 .. .. .. | 12 16 | 26 | 248 | 18*a* | 81 | 71 | 15*b* |
| 8 November, 1911 .. .. .. | 13 43 | 36 | 265 | 17*a* | 90 | 67 | 12*b* |
| 12 November, 1911 .. .. .. | 15 5 | 42 | 248 | 18*a* | 65 | 61 | 22*b* |
| 10 December, 1911 .. .. .. | 15 39 | 47 | 263 | 18*a* | 71 | 79 | 26*b* |
| 20 October, 1912 .. .. .. | 17 20 | 38 | 232 | 17*a* | 32 | 42 | 19*b* |
| Algebraic mean .. .. .. | — | 43 | 254 | 17*a* | 82 | 67 | 18*b* |
| *Class II* | | | | | | | |
| 20 August, 1902 .. .. .. | 21 3 | — | — | — | — | — | — |
| 5 April, 1903 .. .. .. | 23 25 | — | — | — | — | — | — |
| 25 August, 1903 .. .. .. | 22 57 | — | — | — | — | — | — |
| 9 April, 1911 .. .. .. | 22 21 | 61 | 59 | 13*b* | 148 | 216 | 10*a* |
| 30 June, 1911 .. .. .. | 21 50 | 26 | 92 | 24*b* | 31 | 262 | 25*a* |
| 30 September, 1912 .. .. .. | 21 36 | 45 | 53 | 10*b* | 111 | 248 | 28*a* |
| Algebraic mean .. .. .. | — | 41 | 63 | 15*b* | 97 | 233 | 20*a* |
| *Class III* | | | | | | | |
| 2 October, 1911 .. .. .. | 4 8 | 15 | 303 | 17*a* | 25 | 75 | 18*b* |
| 17 January, 1912 .. .. .. | 4 42 | 40 | 313 | 11*a* | 69 | 131 | 12*b* |
| Algebraic mean .. .. .. | — | 27 | 310 | 15*a* | 47 | 117 | 15*b* |

mencement of a magnetic storm of a sort of Saturn ring of electrified particles, lying approximately in the magnetic equator, but at a very great height. This rotating ring would be equivalent to an electrical current, the field of which would bring towards the equator ions which would otherwise have found their way to near a magnetic pole. The S.C. and the movement ending the crest might be associated, the former with the creation, the latter with the dissolution of the ring. There are, however, various apparently irreconcilable phenomena. The crest, when recognizable during a large magnetic storm, seems to have usually but a short existence as compared with the aurora. It seems to be most prominent and long-continued in the case of comparatively trifling storms, and during these aurora is seldom seen in low latitudes.

**11.** Some measurements of S.C. movements are given in Tables 2 and 3, the former devoted to the Antarctic, the latter to other stations. The S.C.'s in Table 2 are divided into three classes; they include six recorded by the 1902–3 Antarctic Expedition. In the case of the latter, the class was unmistakable, but exact measurements were not always possible. The first class includes cases like 8th April, 1911, when the first movement of the oscillation was a fall in all three elements. In the second class the first movement was a rise, as on 9th April, 1911. The third class includes two cases showing intermediate features. All eleven S.C.'s of the first class occurred between 11h and 18h G.M.T. All of the second class occurred between 21h and 24h, and the two of the third class occurred between 4h and 5h. If the hour of the day had nothing to do with the difference in type, it would be very remarkable. As regards the headings in the tables, $\overline{H}$ denotes the resultant of the forces to which the changes in the horizontal components are due, $\psi$ is the inclination of this resultant to astronomical north (East $\equiv 90°$, South $\equiv 180°$), and $\chi$ is the inclination to the horizon of the resultant force to which the complete change is due. The letter *a* assigned to a value of $\chi$ means that the force (on the *north* pole of a magnet) was directed above the horizon, and *b* that it was directed below. It will be noticed that the forces of the first and second phases are nearly oppositely directed. The second phase is the larger in all three cases.

Table 3.

*Particulars of "Sudden Commencements" at Various Observatories.*

| Date | $\overline{H}$ | | | | | | | $\psi$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Buitenzorg | Alibag | Honolulu | Helwan | Agincourt | Eskdalemuir | Sitka | Buitenzorg | Alibag | Honolulu | Helwan | Agincourt | Eskdalemuir | Sitka |
| 1911 | γ | γ | γ | γ | γ | γ | γ | ° | ° | ° | ° | ° | ° | ° |
| 8 April .. | 53 | 41 | 32 | 42 | 31 | 66 | 83 | 347 | 342 | 366 | 343 | 328 | 319 | 357 |
| 9 April .. | 19 | — | 15 | 34 | 68 | 76 | 38 | 371 | — | 359 | 346 | 344 | 343 | 433 |
| 29 May .. | 19 | 16 | 8 | 13 | 28 | 69 | 14 | 350 | 353 | 363 | 319 | 472 | 330 | 329 |
| 9 June .. | 13 | 12 | 8 | 12 | — | 20 | 16 | 349 | 350 | 375 | 350 | — | 335 | 300 |
| 30 June .. | 8 | 8 | 6 | — | 32 | 22 | — | 360 | 344 | 370 | — | 372 | 335 | — |
| 19 August .. | 41 | 19 | — | 17· | 15 | 34 | 41 | 355 | 347 | — | 326 | 302 | 321 | 352 |
| 2 October .. | 17 | — | 7 | 8 | 10 | 14 | 28 | 350 | — | 392 | ? | 344 | 285 | 372 |
| 8 November | 23 | 15 | 12 | 14 | 23 | 30 | 22 | 352 | 354 | 357 | 354 | 439 | 303 | 328 |
| 12 November | 13 | 9 | 6 | 8 | — | 11 | — | 348 | 354 | 366 | 355 | — | 332 | — |
| 10 December | 16 | 11 | 6 | 10 | 5 | 16 | 7 | 351 | 352 | 353 | 342 | 430 | 373 | 296 |
| 1912 | | | | | | | | | | | | | | |
| 17 January .. | 18 | 18 | 9 | 11 | 13 | 15 | 12 | 360 | 354 | 380 | 329 | 353 | 306 | 370 |
| 30 September | 14 | 14 | 10 | 17 | 16 | 24 | — | 352 | 354 | 375 | 348 | 355 | 339 | — |
| 20 October .. | 28 | 22 | 13 | 22 | 30 | 36 | 33 | 350 | 349 | 386 | 351 | 395 | 346 | 513 ? |
| Mean .. | — | — | — | — | — | — | — | 353 | 350 | 370 | 342 | 376 | 328 | 349 |
| Ratio to Antarctic .. | 0·27 | 0·21 | 0·14 | 0·21 | 0·29 | 0·42 | 0·35 | — | — | — | — | — | — | — |

The determination of $\overline{H}$ and $\psi$ in Table 3 was affected by several uncertainties. In the case of the Antarctic, having the complete original curves, any differential time errors affecting the different elements could be determined and allowed for, and in all cases the turning point answering to the end of the first phase seemed identical in time in the three elements. In other cases, excepting Eskdalemuir, there was usually uncertainty as to differential time errors. Not infrequently, so far as could be judged, the turning points were not simultaneous in the different elements. Where H is large, as at Mauritius and Alibag, a D magnetograph is insensitive as a measurer of force, and as the D changes at these stations were very small, the probable percentage error in their measurement

was considerable. The uncertainty affects $\downarrow$ rather than $\bar{H}$. When only one movement was apparent, as at Alibag, the result was unambiguous. But at other places there was sometimes a short preliminary movement, of hardly measurable size. When there were two decided movements, as generally was the case in high latitudes, the data in Table 3 refer to the second movement, which was always the larger. In some cases of very small or confused preliminary movements the measurement represents the change from just before the S.C. to the end of the main movement.

In cases where the resultant horizontal force acted sometimes to the west and sometimes to the east of true north, the angle when easterly has been increased by 360° to secure continuity. The angle for 20th October, 1912, at Sitka was abnormal, and may be given 360° too much; it has been omitted in forming the mean. The comparative uniformity in the values of $\downarrow$ is evidence of a general similarity of type in S.C.'s. There seems nothing corresponding to the difference of type seen in the Antarctic. The ratios in the last line of Table 3 were obtained by dividing the sum of the values of $\bar{H}$ at each station by the sum for the same S.C.'s in the Antarctic. Buitenzorg and Eskdalemuir were the only stations at which all the S.C.'s were represented. But the ratios for the other stations should be fairly comparable, especially as the blanks were few. Obviously the S.C. movement tended to be a minimum at Honolulu, Alibag and Helwan being practically equal and coming next.

Measurements were made of some of the S.C.'s at Mauritius. According to these the amplitude fell between that at Honolulu and at Alibag.

**12.** Reference has already been made to "bay" disturbances. Their form suggests the gradual waxing and waning of a unidirectional current in a fixed circuit, or the gradual approach followed by the recession of a magnet or an electric current equivalent to a magnet. The true cause can hardly, however, be as simple as might be supposed when studying the curves of only a single station. During 1911–12 many disturbances which appeared to be of the "bay" type in ordinary latitudes were associated with larger Antarctic disturbances of a somewhat different character. Examples of these disturbances appear in Figs. 5, 6, and 7. Fig. 5 deals with disturbances recorded between 8h and 13h G.M.T. on 5th May, 1912. The time has been extended to 14h in the first panel to bring out the "bay" character of the largest movement. That panel includes changes in H at Mauritius, Alibag and Helwan, and in N at Eskdalemuir. In all cases there is a marked depression with its trough prior to 12h. An earlier but much shallower depression had its lowest point a little after 9h. The curves, especially that for Alibag, have a gradual slope on which the depressions seem to be superposed. The Eskdalemuir trace shows many minor irregularities.

The second and third panels are confined to the five hours 8h to 13h. The second panel shows the changes in N′ in the Antarctic, in H at Honolulu and Sitka and in N at Buitenzorg. Allowing for the difference in the time scale and in the sensitiveness, the changes in N at Buitenzorg—where the difference between H and N is microscopic—resemble closely those in H at Alibag. The Sitka curve, though more irregular, shows equally the large depression between 11h and 12h. The Honolulu curve, on the other hand, though representing an intermediate latitude, differs in type. Following a smart fall from 8h to 9h, similar to that at Alibag, we have a nearly level trace followed by a marked rise, the maximum appearing near the time when the other stations show a minimum. The Antarctic N′ curve shows a sharp fall and rise about 9½h. The former answers apparently to the rise which terminates the elementary "bay" visible in the Buitenzorg and Alibag curves, so that the narrow Antarctic bay answers to a rudimentary horn or projection visible in all the other curves of the second panel, and in all the curves of the first panel. The main movement in the Antarctic is less simple than elsewhere. Instead of a single oscillation, we have a rise, a larger fall, and a second rise.

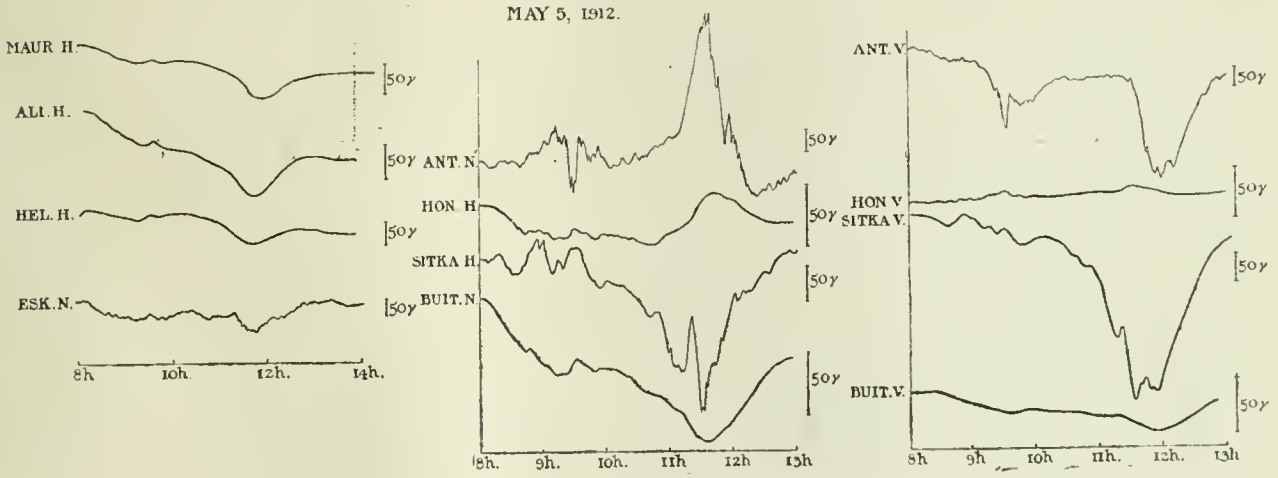



FIG. 5.

The third panel in Fig. 5 shows the changes in V in the Antarctic and at Buitenzorg, Honolulu and Sitka. The original Honolulu and Sitka curves make V increase to those at Honolulu, while the change at Helwan was similar to that at Buitenzorg. Thus we have the curious phenomenon of large changes in V at the

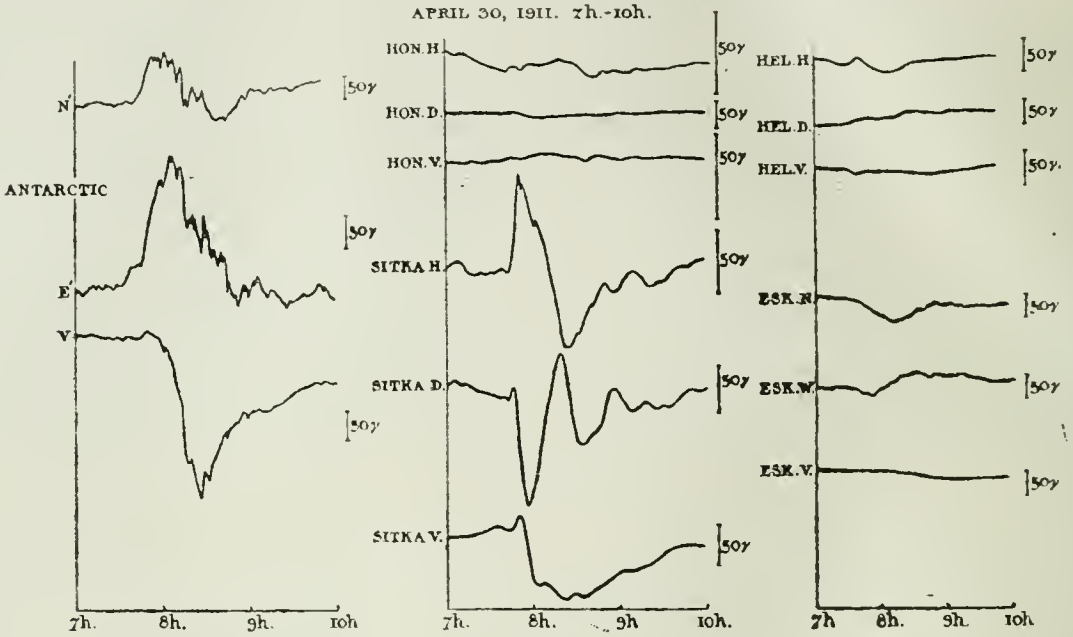



FIG. 6.

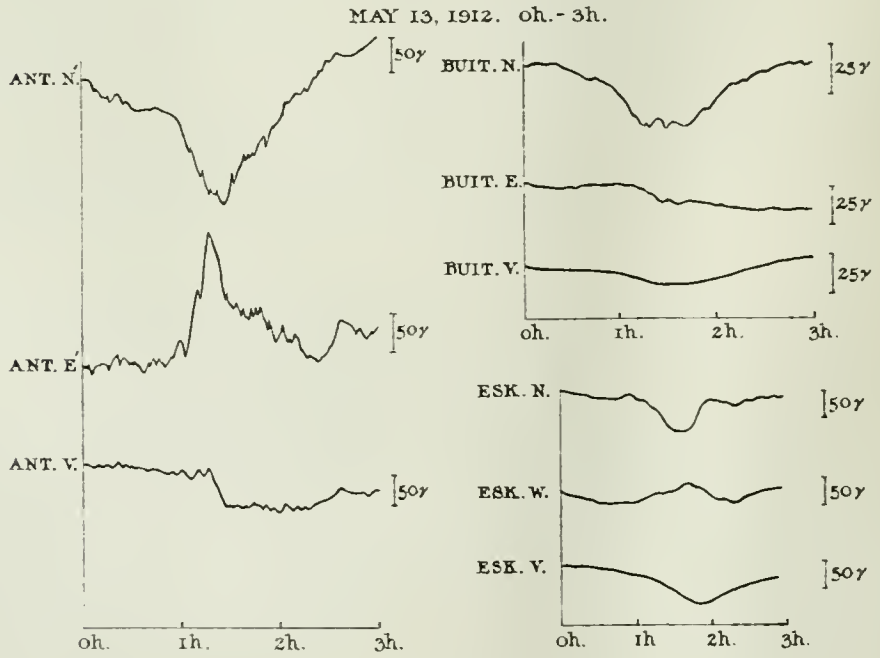



FIG. 7.

down the sheet, but in reproducing the curves the direction has been inverted, so that movement down the sheet means in all cases a force urging a north pole away from the earth's centre. On this occasion the changes in V at Alibag and Eskdalemuir were similar in size extreme northern and southern stations with comparatively trifling changes at intermediate stations.

**13.** Fig. 6 relates to a disturbance between 7h and 10h on 30th April, 1911. The first panel gives the changes in the Antarctic, the N' movement is smaller

than in Fig. 5, but of the same type. The V movement in Fig. 6 is a good representative of short Antarctic disturbances. There was nearly always a principal movement down the sheet, the immediate recovery from which was usually incomplete. The second panel in Fig. 6 shows the trifling changes at Honolulu, and below the much larger changes at Sitka. As in Fig. 5, the V curves have been inverted, so that V increases up the sheet. Also in both the D curves westerly movement is up the sheet. The Honolulu D and V curves are much less disturbed than the H curve, but that is not true of Sitka. The third panel shows the changes at Helwan and Eskdalemuir. The Helwan D curve has been inverted so as to make westerly declination increase up the sheet. The Helwan H curve shows a decided bay which corresponds to a deeper bay in the N curve at Eskdalemuir. As

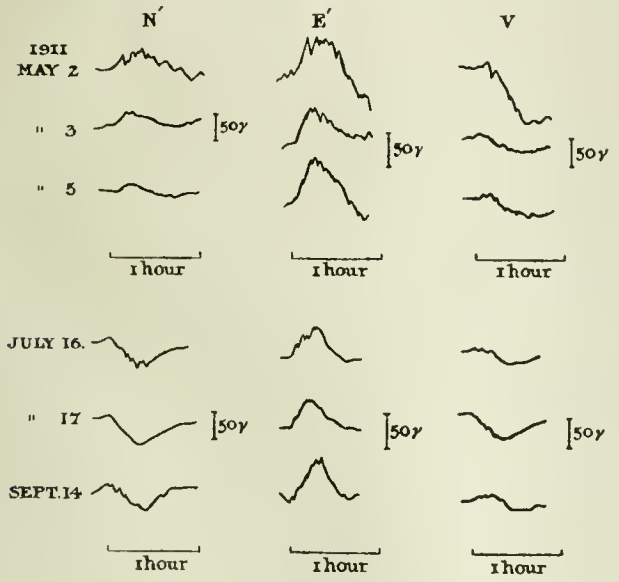



Fig. 8.

is usual on such occasions, the Eskdalemuir V curve is but slightly disturbed. But the disturbance in W, consisting mainly of a small fall and larger rise, is not much less than that in N.

Fig. 7 shows a short disturbance between 0h and 3h on 13th May, 1912. The Antarctic E′ and V curves are of the same type as in Fig. 6, but the N′ curve unlike those in the two previous cases shows only two movements, first a fall and then a rise. In short Antarctic storms N′ movements varied more in type than those in E′ and V; a considerable minority resembled Fig. 7.

The time scales being different at Buitenzorg and Eskdalemuir, the curves from these stations in Fig. 7 are drawn so that the central times are in the same vertical. Both N curves contain a conspicuous bay, the troughs being approximately synchronous with that in the Antarctic N′ curve. The disturbance in W at Eskdalemuir had a range about double that in E at Buitenzorg. The depression shown by the Eskdalemuir V curve is nearly 4 times that apparent at Buitenzorg, and not very much less than that in the Antarctic. It is curious that corresponding to an exceptionally small V range in the Antarctic there should be an exceptionally large range at Eskdalemuir. At Sitka the range in V, though not exceptionally large compared with the ranges in H and D, was nearly double that in the Antarctic.

**14.** Fig. 8 shows in three panels, relating respectively to N′, E′ and V, six examples of small Antarctic disturbances of the same type as in the three previous figures. The disturbances occurred near the same hour of the day, the commencing times (G.M.T.) being approximately as follows: 2nd May, 8h 20m, 3rd May, 7h 0m, 5th May, 6h 20m, 16th July, 5h 30m, 17th July, 5h 35m, and 14th September, 5h 10m. The year in all cases was 1911. The E′ curves show a simple oscillation—with as usual short period oscillations superposed—in which the rise comes first. The V traces are also on the whole similar in type. Following a slight rise or nearly level state there is a decided movement down the sheet (numerical increase), the recovery from which was not usually concluded for a considerable time. The N′ movements are of two nearly opposite types. In the three upper curves, there is a rise followed by a fall as in Figs. 5 and 6, while the three lower curves resemble the N′ curve in Fig. 7. The Eskdalemuir curves for 16th and 17th July and 14th September contained tiny depressions or dimples synchronous with the bays in N′. No bay movements were recognized in the Eskdalemuir curves for 2nd, 3rd, or 5th May, but all showed short period oscillations. Fig. 8 is principally intended to illustrate so-called "repetitions" or cases in which two days—usually successive days—exhibit a closely similar sequence of changes. It is rare for all three elements to show on successive days so striking a similarity in the amplitude, as well as in the type of disturbance, as is exhibited by the curves of 16th and 17th July. There is also much resemblance between the N′ and E′ curves for 2nd and 3rd May. The recurrence of phenomena near the same hour of successive days suggests some direct connection or the persistence of some determining cause. The resemblance, however, between the curves of 3rd and 5th May is at least as close as that between the curves of 2nd and 3rd May, and the curves of the intermediate day did not show the phenomenon. Again the curves of 16th July resemble the curves of 14th September even more closely than they do those of 17th July. The disturbance of 14th September was itself a "repetition" of a disturbance which commenced about 4h 0m on 13th September, but it did not resemble the disturbance of the previous day so closely as it did that of 16th July.

**15.** Table 4 contains data from a large number of short disturbances which in lower latitudes consisted mainly of "bays" in H or N. All declination data have been expressed in terms of the equivalent force. It is difficult except in the case of S.C.'s to assign a definite time of commencement to a disturbance, and the end is generally even less definite. Thus the starting and stopping times have been regarded as occurring at exact hours G.M.T. The starting time and the duration are given in the table. The times

TABLE 4.

*Particulars of Short Disturbances at Various Stations.*

| Date | Begins | Length | Antarctic | | | Mauritius | | Buitenzorg | | | Alibag | | | Honolulu | | | Helwan | | | Agincourt | | Eskdalemuir | | | Sitka | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N′ | E′ | V | H | D | N | E | V | H | D | V | H | D | V | H | D | V | H | D | N | E | V | H | D | V |
| 1911 | h | Hours | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ |
| 30 April .. .. .. | 7 | 3 | 143 | 234 | 287 | 24 | 27 | 75 | 13 | 28 | 43 | — | — | 16 | 12 | 6 | 21 | 35 | 12 | 32 | 16 | 54 | 50 | 18 | 140 | 159 | 100 |
| 16 May .. .. .. | 2 | 2 | 155 | 202 | 301 | — | 21 | 22 | 10 | 6 | 22 | — | — | — | — | — | 14 | 18 | 3 | 53 | 69 | 51 | 21 | 28 | 66 | 90 | 21 |
| 16 May .. .. .. | 4 | 4 | 276 | 559 | 388 | 25 | 29 | 68 | 13 | 8 | 17 | — | — | — | — | — | 37 | 29 | 26 | 111 | 131 | 81 | 83 | 27 | 127 | 150 | 135 |
| 21 May .. .. .. | 9 | 3 | 250 | 373 | 337 | 40 | 15 | 48 | 15 | 18 | 56 | 20 | 7 | 17 | 11 | 5 | — | — | — | — | — | 57 | 46 | 11 | 112 | 90 | 151 |
| 5 June .. .. .. | 7 | 3 | 77 | 324 | 235 | 40 | 14 | 73 | 18 | 24 | 38 | — | — | — | — | — | 27 | 28 | 8 | 62 | 94 | 53 | 33 | 5 | — | — | — |
| 3 July .. .. .. | 7 | 3 | 242 | 617 | 426 | 16 | 23 | 35 | 11 | 13 | 18 | 11 | 9 | 20 | 11 | 6 | — | — | — | 32 | 66 | 23 | 19 | 6 | 45 | 111 | 61 |
| 11 July .. .. .. | 6 | 3 | 126 | 189 | 265 | 21 | 11 | 30 | 18 | 8 | 15 | 12 | 16 | — | — | — | — | — | — | 38 | 43 | 31 | 19 | 6 | 82 | 103 | 43 |
| 12 July .. .. .. | 7 | 3 | 125 | 154 | 113 | 15 | 14 | 35 | 10 | 8 | — | — | — | — | — | — | — | — | — | — | — | 31 | 26 | 10 | 69 | 44 | 42 |
| 20 July .. .. .. | 6 | 3 | 97 | 163 | 169 | 17 | 15 | 34 | 26 | 9 | 14 | 11 | 25 | — | — | — | — | — | — | 28 | 63 | 39 | 16 | 8 | 68 | 115 | 56 |
| 31 July .. .. .. | 8 | 2 | 135 | 198 | 218 | 16 | 32 | 31 | 4 | 11 | 24 | — | — | — | — | — | — | — | — | 20 | 59 | 36 | 23 | 5 | 80 | 61 | 49 |
| 24 August .. .. .. | 8 | 2 | 233 | 234 | 285 | 28 | 23 | 25 | 7 | 10 | 16 | — | — | 28 | 14 | 12 | 24 | 9 | — | 37 | 82 | 44 | 34 | 8 | 77 | 117 | 79 |
| 31 August .. .. .. | 7 | 3 | 172 | 174 | 94 | 19 | 30 | 43 | 15 | 16 | 16 | — | — | — | — | — | — | — | — | 33 | 109 | 43 | 38 | 11 | 83 | 127 | 117 |
| 1912 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 January .. .. | 5 | 4 | 201 | 426 | 132 | — | — | 56 | 22 | 21 | 31 | 10 | 17 | 25 | 20 | 10 | — | — | — | 42 | 117 | 53 | 33 | 8 | 120 | 168 | 99 |
| 5 May .. .. .. | 8 | 2 | 144 | 151 | 211 | 34 | 19 | 58 | 11 | 24 | 56 | 15 | 10 | 29 | 14 | 10 | 21 | 35 | 28 | 35 | 33 | 55 | 34 | 7 | 69 | 115 | 53 |
| 5 May .. .. .. | 10 | 3 | 398 | 262 | 263 | 63 | 21 | 54 | 20 | 22 | 68 | 23 | 9 | 40 | 13 | 11 | 63 | 14 | 33 | 55 | 141 | 85 | 70 | 9 | 221 | 173 | 282 |
| 13 May .. .. .. | 0 | 3 | 225 | 191 | 82 | 16 | — | 32 | 19 | 18 | 27 | — | — | — | — | — | — | — | — | 95 | 255 | 74 | 37 | 70 | 223 | 108 | 153 |
| 2 June .. .. .. | 6 | 3 | 102 | 176 | 152 | 7 | 8 | 25 | 8 | 7 | 11 | — | — | — | — | — | — | — | — | 30 | 46 | 19 | 19 | 3 | — | — | — |
| 3 June .. .. .. | 5 | 3 | 78 | 196 | 272 | 19 | — | 42 | 14 | 9 | 23 | 22 | 13 | — | — | — | — | — | — | 33 | 56 | 36 | 43 | 7 | — | — | — |
| 8 June .. .. .. | 2 | 3 | 116 | 101 | 55 | 12 | 15 | — | — | — | 25 | — | — | — | — | — | 22 | 16 | 11 | 49 | 67 | 35 | 44 | 17 | 77 | 62 | 49 |
| 8 June .. .. .. | 6 | 2 | 78 | 163 | 86 | 16 | 5 | — | — | — | 20 | — | — | — | — | — | 21 | 19 | 22 | 48 | 97 | 45 | 31 | 4 | 86 | 159 | 109 |
| 1 August .. .. .. | 3 | 3 | 142 | 248 | 201 | 22 | 19 | 52 | 28 | 17 | — | — | — | — | — | — | 33 | 19 | 12 | 39 | 71 | 69 | 61 | 18 | 109 | 161 | 148 |
| Quiet day Range ÷ Disturbed day Range .. | | | 0·12 | 0·05 | 0·06 | 0·27 | 0·74 | 0·36 | 0·74 | 0·66 | 0·49 | 0·83 | 0·94 | 0·09 | 0·13 | 0·15 | 0·49 | 0·86 | 0·51 | 0·09 | 0·11 | 0·28 | 0·26 | 0·27 | 0·04 | 0·04 | 0·04 |
| D ÷ H or E ÷ N .. .. .. .. .. | | | | 1·52 | | | 0·77 | | 0·34 | | | 0·44 | | | 0·54 | | | 0·89 | | | 1·84 | | 0·77 | | | 1·14 | |
| H at station ÷ $\bar{H}$ in Antarctic .. .. .. | | | | — | | | 0·10 | | 0·15 | | | 0·11 | | | 0·07 | | | 0·12 | | | 0·32 | | 0·20 | | | 0·50 | |
| V at station ÷ V in Antarctic .. .. .. | | | | — | | | — | | 0·06 | | | 0·05 | | | 0·03 | | | 0·07 | | | — | | 0·06 | | | 0·44 | |

## TABLE 5.

*Particulars of Long Disturbances at Various Stations.*

| Date | Begins | Length | Antarctic | | | Mauritius | | Buitenzorg | | | Alibag | | | Honolulu | | | Helwan | | | Agincourt | | Eskdalemuir | | | Sitka | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N′ | E′ | V | H | D | N | E | V | H | D | V | H | D | V | H | D | V | H | D | N | E | V | H | D | V |
| 1911 | h | Hours | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ | γ |
| 8 April .. .. .. | 11 | 28 | 63 | 118 | 274 | 159 | 57 | 276 | 50 | 47 | 191 | 44 | 28 | 206 | 66 | 43 | 188 | 88 | 44 | 500 | 368 | 261 | 227 | 221 | 1,014 | 452 | 759 |
| 9 April .. .. .. | 22 | | 368 | 238 | 134 | 42 | 29 | 75 | 21 | 33 | 59 | — | — | 46 | 25 | 19 | 51 | 49 | 21 | 117 | 121 | 145 | 73 | 37 | 202 | 120 | 207 |
| 14 May .. .. .. | 16 | 19 | 237 | 484 | 236 | 55 | 61 | 140 | 43 | 38 | — | — | — | 147 | 57 | 33 | 112 | 79 | 36 | 250 | 231 | 192 | 115 | 165 | 586 | 261 | 361 |
| 9 June .. .. .. | 16 | 20 | 258 | 375 | 184 | 42 | 42 | 114 | 25 | 24 | 51 | 41 | 52 | 100 | 83 | 41 | 87 | 56 | — | 200 | 205 | 115 | 124 | 92 | 160 | 173 | 302 |
| 30 June .. .. .. | 21 | 12 | 343 | 229 | 134 | 22 | 18 | 99 | 37 | 22 | 43 | 37 | 35 | 57 | 30 | 21 | — | — | — | 58 | 91 | 41 | 60 | 25 | — | — | — |
| 28 July .. .. .. | 10 | 24 | 342 | 311 | 271 | 48 | 46 | 121 | 32 | 39 | 65 | — | — | 65 | 50 | 18 | 74 | 88 | 32 | 100 | 127 | 237 | 134 | 100 | 213 | 174 | 375 |
| 19 August .. .. .. | 12 | 21 | 181 | 236 | 84 | 41 | 34 | 67 | 37 | 23 | 42 | — | — | — | — | — | 61 | 62 | 19 | 69 | 115 | 68 | 88 | 28 | 88 | 117 | 71 |
| 23 August .. .. .. | 8 | 52 | 454 | 523 | 338 | 125 | 68 | 140 | 52 | 46 | 117 | — | — | 86 | 86 | 29 | 108 | 71 | 39 | 155 | 290 | 270 | 150 | 240 | 573 | 287 | 559 |
| 19 September .. .. | 18 | 54 | 486 | 403 | 257 | 75 | 53 | 204 | 58 | 38 | 112 | — | — | 115 | 54 | 36 | 99 | 63 | 29 | 283 | 326 | 215 | 155 | 161 | 489 | 330 | 626 |
| 10 October .. .. .. | 12 | 24 | 330 | 467 | 143 | 70 | 58 | 127 | 41 | 27 | 55 | — | — | 148 | 68 | 35 | 89 | 95 | 25 | 291 | 245 | 183 | 317 | 233 | 697 | 299 | 405 |
| 8 November .. .. | 12 | 20 | 324 | 308 | 210 | 34 | 58 | 56 | 73 | 60 | 53 | 22 | 12 | 46 | 36 | 20 | 61 | 40 | 20 | 49 | 109 | 62 | 92 | 26 | 57 | 69 | 76 |
| 12 November .. .. | 15 | 39 | 424 | 456 | 229 | 69 | 53 | 109 | 39 | 39 | 70 | — | — | 55 | 24 | 20 | 74 | 49 | 20 | 71 | 109 | 130 | 131 | 109 | 181 | 194 | 240 |
| 6 December .. .. | 11 | 15 | 341 | 474 | 317 | 89 | — | 61 | 36 | 22 | 89 | 20 | 11 | 36 | 26 | 11 | 124 | 79 | 28 | 84 | 103 | 110 | 142 | 116 | 191 | 183 | 113 |
| 10 December .. .. | 15 | 35 | 444 | 727 | 382 | 162 | 81 | 290 | 104 | 58 | 178 | 58 | 29 | 167 | 42 | 29 | 156 | 75 | 27 | 235 | 326 | 191 | 178 | 174 | 729 | 379 | 689 |
| 1912 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 January .. .. | 4 | 14 | 147 | 315 | 153 | 50 | 51 | 74 | 29 | 30 | 74 | 26 | 18 | 30 | 14 | 12 | 48 | 29 | 30 | 36 | 63 | 36 | 29 | 11 | 49 | 70 | 109 |
| 15 April .. .. .. | 1 | 13 | 207 | 248 | 139 | 70 | 24 | 156 | 46 | 42 | 91 | — | — | 102 | — | — | 56 | 53 | 15 | 147 | 134 | 123 | 69 | 45 | 599 | 291 | 510 |
| 12 May .. .. .. | 0 | 14 | 300 | 226 | 116 | 60 | 26 | 106 | 28 | 22 | 69 | — | — | 83 | — | — | — | — | — | 67 | 202 | 109 | 98 | 34 | 144 | 197 | 266 |
| 13 May .. .. .. | 0 | 11 | 382 | 447 | 306 | 58 | 27 | 123 | 24 | 38 | 73 | — | — | — | — | — | — | — | — | 93 | 251 | 98 | 85 | 80 | 305 | 216 | 431 |
| 31 July .. .. .. | 14 | 18 | 196 | 323 | 324 | 41 | 32 | 59 | 49 | 30 | 38 | — | — | — | — | — | 49 | 55 | 22 | 91 | 71 | 98 | 125 | 53 | 135 | 176 | 217 |
| 18 August .. .. | 14 | 16 | 188 | 302 | 82 | 34 | 14 | 42 | 50 | 41 | 50 | — | — | 55 | 56 | 28 | 61 | 39 | 17 | 99 | 97 | 93 | 93 | 58 | — | — | — |
| 17 September .. | 11 | 12 | 256 | 302 | 119 | 85 | 46 | 65 | 28 | 26 | 79 | 25 | 21 | 55 | 29 | 18 | 110 | 82 | 42 | 95 | 94 | 245 | 172 | 77 | — | — | — |
| 18 September .. .. | 0 | 14 | 261 | 227 | 89 | 64 | 29 | 64 | 32 | 22 | 34 | — | — | 35 | 12 | 10 | 32 | 72 | 22 | 42 | 80 | 82 | 65 | 24 | 93 | 107 | 137 |
| 24 September .. .. | 0 | 14 | 351 | 244 | 210 | 74 | 41 | 152 | 50 | 29 | 96 | — | — | 96 | 22 | 17 | 62 | 44 | 15 | 109 | 253 | 126 | 127 | 60 | 457 | 291 | 696 |
| 24 September .. .. | 14 | 12 | 265 | 200 | 103 | 32 | 34 | 57 | 39 | 7 | 24 | — | — | — | — | — | 50 | 47 | 18 | 36 | 118 | 169 | 116 | 64 | — | — | — |
| 30 September .. .. | 21 | 21 | 226 | 288 | 180 | 96 | — | 137 | 68 | 33 | 103 | 31 | 34 | 114 | 34 | 22 | 86 | 46 | 15 | 89 | 107 | 108 | 69 | 55 | 196 | 173 | 251 |
| 12 October .. .. .. | 20 | 16 | 216 | 246 | 109 | 36 | 46 | 53 | 34 | 32 | 46 | — | — | — | — | — | 44 | 42 | 21 | 36 | 97 | 77 | 76 | 48 | — | — | — |
| 14 October .. .. .. | 6 | 24 | 336 | 477 | 162 | 62 | 46 | 75 | 52 | 48 | 77 | — | — | — | — | — | 59 | 81 | 26 | 85 | 179 | 185 | 219 | 102 | 117 | 158 | 201 |
| Quiet day Range ÷ Disturbed day Range .. | | | 0·22 | 0·18 | 0·21 | 0·29 | 0·66 | 0·32 | 0·70 | 0·56 | 0·43 | 0·75 | 0·71 | 0·15 | 0·78 | 0·76 | 0·31 | 0·60 | 0·67 | 0·22 | 0·23 | 0·22 | 0·27 | 0·17 | 0·07 | 0·16 | 0·03 |
| D ÷ H or E ÷ N .. .. .. .. .. | | | | 1·10 | | 0·67 | | | 0·39 | | | 0·35 | | | 0·49 | | | 0·76 | | 1·29 | | | 0·88 | | | 0·65 | |
| H at Station ÷ H in Antarctic .. .. | | | | — | | 0·17 | | | 0·26 | | | 0·20 | | | 0·19 | | | 0·21 | | 0·45 | | | 0·40 | | | 0·80 | |
| V at Station ÷ V in Antarctic .. .. .. | | | | — | | — | | | 0·17 | | | 0·12 | | | 0·12 | | | 0·13 | | — | | | 0·46 | | | 1·57 | |

of occurrence of the maximum and minimum were usually different for the different elements. Thus the ranges given in the table do not as a rule represent components of a movement beginning and ending at definite times. No V curves were available for Mauritius or Agincourt, and frequently only H curves for Alibag. The average disturbance in Table 4 had a length of about 3 hours, and the natural diurnal variation in 3 hours may be considerable. Some idea is thus desirable of what change might have been expected in the absence of disturbance. Each case was really considered separately, but this is not the place for details. The quantity (quiet day range) ÷(disturbed day range) given in the table was obtained by dividing the sum of the calculated quiet day changes for all the occasions included at the particular station, by the corresponding sum of the observed changes. The great majority of the selected disturbances occurred in May, June or July (Antarctic mid-winter), and during a few hours of the (Greenwich) forenoon. Thus the sum of the quiet day ranges was a less heterogeneous assemblage than might appear at first sight. It is clear that in the Antarctic, also at Honolulu and Agincourt and especially at Sitka, the regular diurnal change to be expected during the average disturbance of Table 4 was so small as to be almost negligible. But at Mauritius, Buitenzorg, Alibag and Helwan the normal day change in D or E would represent a large fraction of the observed range. The normal day change in H or N at these stations, though relatively less, is also considerable. It would not be correct to regard a disturbance as measured by the excess of the observed over the normal range. An oscillatory movement is naturally assisted at one stage by the normal change, but it is opposed at another stage, and much may depend on when the turning point happens to fall. As a matter of fact, however, during the majority of these short disturbances the D range at the stations in lower latitudes appeared largely due to the regular diurnal variation. The excess of the disturbance in H or N over that in D or E at these stations, especially at Mauritius, was really larger than Table 4 might suggest.

Even if we wholly neglected the contribution from the regular diurnal variation, we should infer from the values of D/H and E/N that disturbance in H was largely dominant at all stations from Mauritius to Honolulu. But in the Antarctic and at Sitka, and what is more surprising at Agincourt, the component perpendicular to the magnetic meridian was decidedly the more disturbed. In the comparisons instituted between the values of $\bar{H}$ and V at individual stations and the Antarctic, only those disturbances were considered which were represented at the station in question. H here means the resultant of the H and D (or N and E) changes treated as if components of one and the same force.

**16.** The average long magnetic storm—and a storm may last several days—appears to be a confused assemblage of principal oscillations, having smaller short-period oscillations superposed on them, often with "bays" and quieter interludes thrown in. We know to-day that they are not absolutely lawless phenomena, and presumably further study will make order visible where as yet disorder seems to prevail. A few general characteristics have been detected. Vertical force changes show a marked dependence on local time. At Kew and elsewhere in Western Europe it is usual on disturbed days for V to be enhanced in the afternoon and depressed in the early morning. At the commencement of a storm, at least when there is an S.C., H tends to rise. After a time, varying from storm to storm, elevation is succeeded by depression.

In most cases after a storm has been some hours in progress H is markedly below its normal value. A recovery finally sets in, which may be conspicuous long after large oscillations have ceased.

Table 5 contains data, similar in kind to those in Table 4, for the principal magnetic storms of 1911 and 1912 of which records were obtained in the Antarctic. As the dates will show, a number of them were associated with the S.C. movements already enumerated. An exact number of hours was allotted to each storm. The length allotted was in some cases determined partly by the curves available from the co-operating stations. If complete records had been to hand from all the stations, some of the intervals might with advantage have been longer. In a few cases, especially at Sitka, the ranges in Table 5 are underestimates, the trace having gone beyond the limits of registration. This is true of the largest range included in the table, 1014γ in H at Sitka on 8th April, 1911. As in Table 4, the range represents the difference between the extreme values recorded during the interval in the element, irrespective of the times of occurrence of the extremes in the other elements. Thus the ranges do not usually represent strictly synchronous movements in the different elements. The quantities given at the foot of the table were arrived at in the same way as in Table 4. As before, only H and D curves were available for Mauritius and Agincourt, and usually only H curves for Alibag.

A study of the table will soon bring home the fact that there is much which appears fortuitous in the development of large storms in different parts of the world. There is on the whole a considerable parallelism between the amplitudes of the several storms as recorded at Mauritius, Buitenzorg, Alibag and Helwan. But there is much less parallelism between these stations on the one hand and Agincourt and Sitka on the other. Take, for instance, the storms commencing on 18th September and 24th September, 1912, at 0h and lasting 14 hours. The ranges during the second storm are decidedly the larger, but their excess at Agincourt and Sitka is out of all proportion greater than their excess in the Antarctic or at Mauritius. So again the disturbance on 10th December, 1911, is everywhere greater than that on 12th November, but the excess is relatively much less in the Antarctic and at Eskdalemuir than it is at the other stations, especially at Sitka.

It is a curious fact that the values obtained in Table 5 for ($\bar{H}$ at Station)÷(H in Antarctic) are nearly or exactly the same as those obtained in Table 3 for the S.C. movements at Buitenzorg, Alibag, Helwan and Eskdalemuir. And if we were to arrange the stations in order according to the size of this ratio, we should

obtain exactly the same order from Tables 4 and 5, except that Mauritius and Honolulu would change places. The pre-eminence of the Antarctic disturbances is, however, notably less for the long disturbances of Table 5 than for the short disturbances of Table 4. This is especially true of vertical force. At Sitka the development of the vertical force disturbance during the long storms is so great that it actually exceeds that in the Antarctic. Even in the horizontal plane the development of disturbance at Sitka is surprising when we remember that the selection of the storms was based on the Antarctic curves without any regard to Sitka.

**17.** Occasionally a marked similarity is apparent in the development of even a long disturbance at different stations. This is illustrated by Fig. 9, which refers to a nine-hour interval commencing near 13h on 17th September, 1912. The figure includes the H or N curves from Mauritius, Alibag, Helwan and Eskdalemuir in the one panel, and in the other the N′ curve from the Antarctic, the N curve from Buitenzorg, and the H curve from Honolulu. All the curves in the first panel show six oscillations with crests approximately at 13h 55m, 14h 45m, 15h 45m, 17h 15m, 18h 55m, and 20h 25m. These six oscillations are also clearly shown in the second panel at Buitenzorg. The first three are clearly shown, and possibly also the fourth if not the fifth, in the Antarctic; but at Honolulu only the first two are recognizable. The sixth movement is indeed represented in the Antarctic and at Honolulu, but is there inverted. At Sitka record was missing until 16h 50m. There was a large movement there answering to the sixth oscillation, but it was in the same direction as in the Antarctic and at Honolulu. At Agincourt (curves not reproduced) the three earliest of the six movements are represented but are inverted, i.e. minima appear in H at the times of the maxima at other stations. These Agincourt movements were, however, much interfered with by short-period oscillations. Later there were prominent maxima in H at Agincourt, at about 18h 55m, and 19h 55m, with a pretty prominent *minimum* at 20h 30m. The relative amplitudes of the first three oscillations were very similar at the different stations. If we call the mean of the three amplitudes at each station 100, the relative amplitudes of the three were as follows :—

| Number | Antarctic | Mauritius | Buitenzorg | Alibag | Helwan | Eskdalemuir | Mean |
|---|---|---|---|---|---|---|---|
| 1 | 78 | 57 | 59 | 58 | 64 | 57 | 66 |
| 2 | 116 | 103 | 119 | 111 | 106 | 115 | 114 |
| 3 | 107 | 140 | 122 | 130 | 130 | 128 | 120 |

The mean represents the result obtained when the amplitudes at all the stations were summed and the three sums intercompared.

**18.** Another remarkable example of a succession of oscillations, identifiable at a number of stations, occurred between 14h and 17½h on 24th September, 1912. Fig. 10 shows the records from Mauritius (H), Alibag (H), Helwan (H), and Eskdalemuir (N and W). The time scale shown applies to the last three stations; that for Mauritius is somewhat opener. Nine peaks can easily be identified at these stations, and also in N at Buitenzorg. The first four and the last can be identified in the Honolulu H curve, and the first three in the declination curves (but not the H curves) at Agincourt and Sitka. The movements were by no means pure oscillations about a normal position. Most of the curves show a slope, representing a gradual change of force, on which the short-period movements

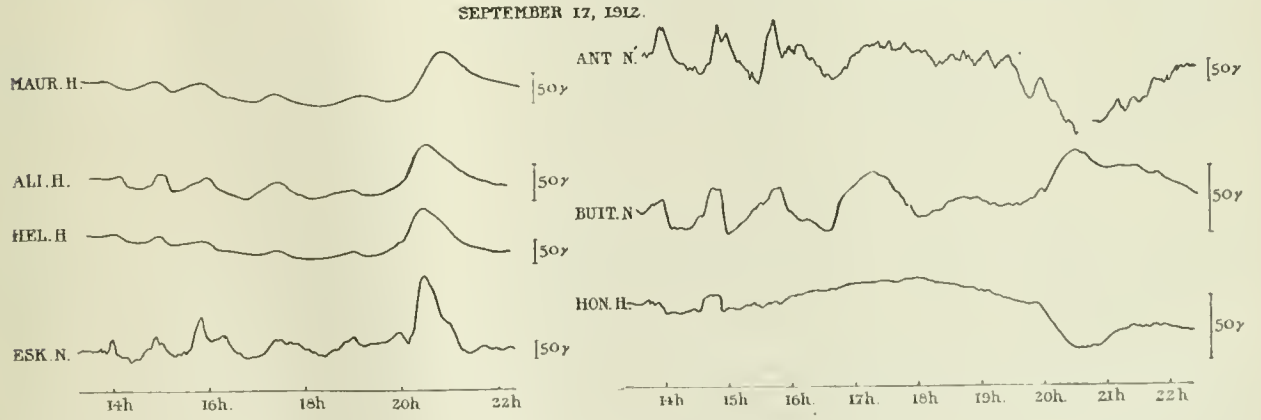



FIG. 9.

were superposed. Also, corresponding up and down movements were by no means equal. If, however, we accept the sum of each pair of up and down movements as a measure of the amplitude of the oscillation, we find that the development of the successive oscillations pursued a closely similar course at all the stations. Taking the mean of the amplitudes from the H curves

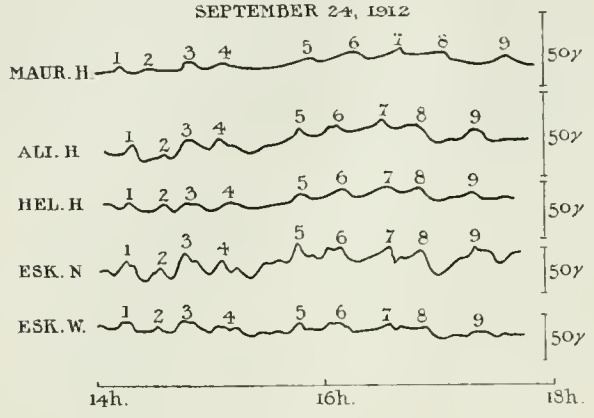



FIG. 10.

at Mauritius, Alibag and Helwan, the N curve at Buitenzorg, and the N and W curves at Eskdalemuir as representing 100 for each oscillation, we obtain for the relative amplitudes at the several stations the following figures:—

| Oscillation number .. .. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mauritius .. .. | H | 43 | 39 | 45 | 53 | 35 | 58 | 43 | 35 | 41 | 44 |
| Buitenzorg .. .. | N | 96 | 67 | 83 | 91 | 78 | 76 | 89 | 71 | 78 | 81 |
| Alibag .. .. | H | 67 | 55 | 62 | 74 | 65 | 64 | 66 | 71 | 57 | 65 |
| Helwan .. .. | H | 80 | 108 | 85 | 92 | 75 | 84 | 82 | 85 | 85 | 85 |
| Eskdalemuir .. .. | N | 206 | 194 | 210 | 180 | 233 | 218 | 212 | 230 | 244 | 215 |
| ,, .. .. | W | 109 | 136 | 117 | 111 | 113 | 100 | 108 | 108 | 95 | 110 |

The oscillations were invariably largest at Eskdalemuir and least at Mauritius, and were decidedly less at Alibag than at Buitenzorg or Helwan. The amplitudes, it must be remembered, were not large, and high accuracy cannot be claimed for individual figures.

**19.** If the electric current causing a magnetic storm varied only in intensity, i.e. if it described an invariable path, and merely waxed and waned, we should have the disturbances at a series of stations pursuing a parallel course. Except in so far as the regular diurnal variation intervened, all turning points would occur simultaneously. This ideal state of matters is suggested by the earlier movements on 17th September, 1912 (see Fig. 9), but the contrast exhibited by the later movements shows that if this were the commencing state of matters it did not endure. This raises the question of what should occur at a single station when differences appear in the times of the turning points at different stations. It is clear on reflection that identity in the times of the turning points in the curves of different elements is not to be expected under such conditions. If a current in a fixed circuit waxes and wanes, the disturbing force at a fixed point will be in a fixed direction. This means that the three rectangular components will maintain a constant ratio to one another. Their times of maximum and minimum must under such conditions be identical. But if the position of the distant current varies, the direction of the resultant disturbing force will naturally vary, and so the rectangular components will cease to stand in a constant ratio to one another. There is then no reason why the maxima and minima in the several elements should be simultaneous.

A convenient way of showing changes in the forces in the horizontal plane is afforded by the so-called vector diagram. The departures of the two rectangular components, say N and E, from their accepted normal values are plotted with two rectangular axes. The successive points thus arrived at being connected by straight lines, we get what is known as the vector diagram. It has the property that if any one of the successive points is connected with the origin, the connecting line represents in magnitude and direction the resultant at the moment of the disturbing forces to which the departure from the assumed normal is due. Fig. 11 gives vector diagrams for the disturbing forces in the horizontal plane at the Antarctic station, and at Mauritius, Buitenzorg, Alibag, Honolulu, Helwan, Agincourt, Falmouth, and Sitka between 19h 40m and 21h 40m on 17th September, 1912. This covers the time of the final big oscillation shown in Fig. 9. The origin of co-ordinates in each case answers to the mean value of the magnetic elements during the two hours in question. The shape of the diagram is independent of the choice made of normal values for the magnetic elements. A difference in the choice is merely equivalent to a bodily shift of the diagram relative to the origin of co-ordinates.

The force scale in Fig. 11 is in all cases the same. It is shown by the arms of the cross drawn at every origin. Each arm represents 10γ. North is up the sheet, and east to the right. The curves were all measured at 5-minute intervals, and all the readings have been used, without any smoothing, in constructing the Falmouth diagram. But the points answering to 19h 55m and 21h 10m fell so close together as not to be separable. At the other stations, with the exception of the Antarctic, it was necessary to omit many or all of the alternate readings—those at 19h 45m, 19h 55m, etc.—to avoid overcrowding. In the Antarctic all the readings were used, but they were

first smoothed by the formula $(a+2b+c)\div 4$, where $a$, $b$, $c$, represent any three successive readings.

The Falmouth diagram is the largest and most regular. The Kew and Eskdalemuir diagrams (not reproduced) were very similar to that at Falmouth, but larger areas were enclosed, especially at Eskdalemuir.

**20.** If we imagine a point to travel round the Falmouth diagram, starting at 19h 40m and reaching each point at the time it answers to, it makes a complete circuit between 19h 55m and 21h 10m, i.e. in 75 minutes, and the circuit is described in the anticlockwise (or *a.c.*) direction. All the other diagrams, except perhaps is presumably true of Kew, Falmouth and Eskdalemuir. I am not, however, able to say whether the directions of rotation appearing in Fig. 11 are normal for the other stations.

The large size of the area within the Kew, Falmouth and Eskdalemuir diagrams as compared with the others is presumably an accident of the particular storm. There seems no *a priori* reason to expect a special development of rotating storms in the United Kingdom.

A discussion of theories presupposes a full knowledge or complete statement of the facts by which alone

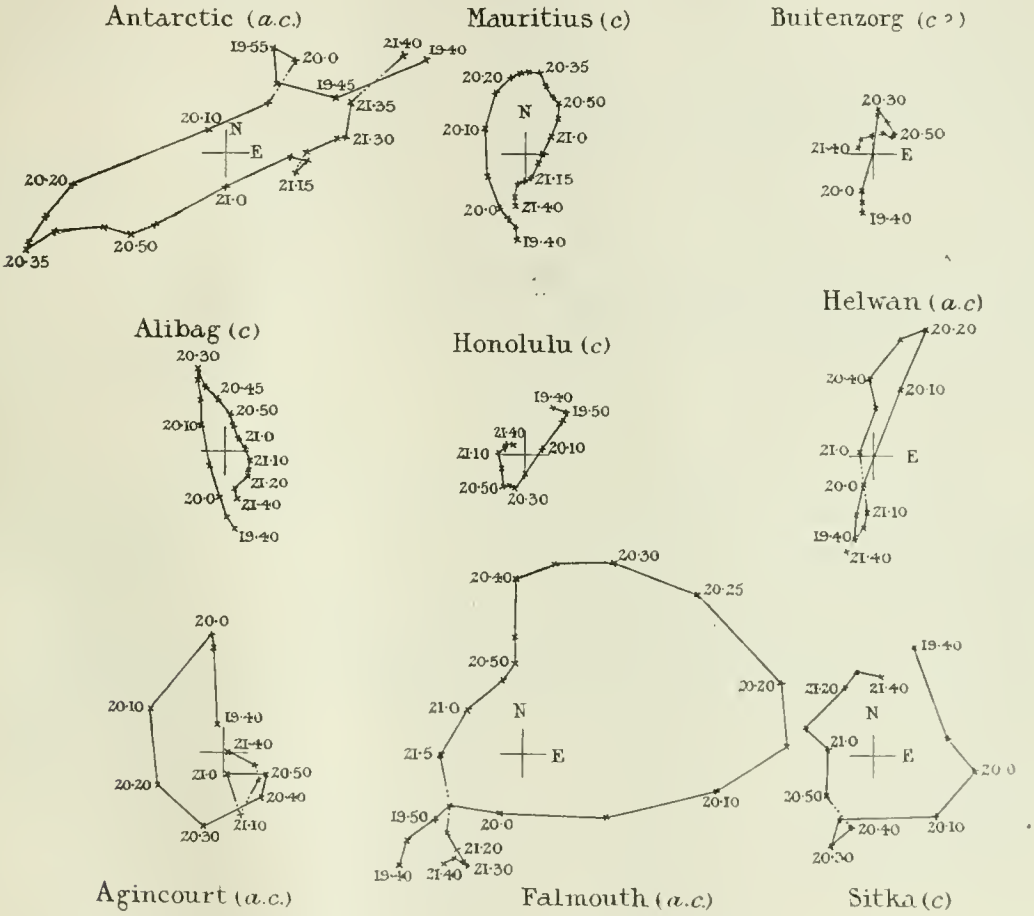



FIG. 11.

that for Buitenzorg, are of an analogous type, though in most the circuit is not quite complete. But the directions in which the diagrams are described vary. The direction of description is clockwise (*c*) at Mauritius, Alibag, Honolulu and Sitka, but *a.c.* in the Antarctic and at Helwan, Agincourt and Falmouth. The Kew and Eskdalemuir diagrams were described *a.c.* as at Falmouth.

Rotatory storms, such as that shown in Fig. 11, are by no means rare. They were first detected by Mr. R. B. Sangster * from a study of Greenwich disturbances. He found that the direction in which the diagram is described varies with the hour of the day, the *a.c.* direction being very dominant after 15h, and especially so between 19h and 21h. What is true of Greenwich they can be tested. To have dealt with both facts and theories would have made an undue claim on the patience of the audience. I have thus confined myself almost entirely to facts, considering them the most suitable material for an occasion of this kind.

I am indebted to the Director of the Meteorological Office for permission to utilize hitherto unpublished data from the observatories of the office, and to the Committee of the Captain Scott Antarctic Fund for permission to include many data derived from the records obtained in the Antarctic in 1911 and 1912. I would also repeat my acknowledgments of the kindness of the Rev. Walter Sidgreaves, S.J., in sending a number of Stonyhurst curves, enabling a direct comparison to be made of Stonyhurst and Kew.

* *Proceedings of the Royal Society*, A, vol 84, p. 85.

# BENEVOLENT FUND.

21ST ANNUAL GENERAL MEETING, 29 MAY, 1919.

(Held at the Royal Society of Arts.)

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 3.30 p.m.

The Minutes of the Annual General Meeting of the 30th May, 1918, were taken as read, and were confirmed and signed.

The President moved, and Mr. W. R. Rawlings seconded, that the Report (see below) of the Committee of Management and the Statement of Accounts for the year 1918 (see page 337) be adopted. After a few remarks by Mr. W. B. Esson, the motion was unanimously carried.

On the motion of the President, seconded by Mr. J. E. Kingsbury, Mr. Sidney Sharp and Mr. J. Attfield, F.C.A., were re-elected Honorary Auditors.

The Committee of Management for the year 1919–20 was reported to be as follows:—

The President (*ex-officio*).

| | |
|---|---|
| Mr. J. Devonshire<br>Mr. D. N. Dunlop<br>Mr. W. Judd<br>Mr. W. Lang<br>Mr. G. Scott Ram<br>Sir W. Slingo | Representing the Council. |
| Mr. C. C. Hawkins<br>Mr. H. W. Kolle<br>Mr. J. H. Rider | Representing the Contributors. |

and the Chairman of each Territorial Centre in the United Kingdom.

The meeting then terminated.

## REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1918.

### CAPITAL.

The Capital Account stood on the 31st December, 1918, at £5,709 9s. 6d., all of which is invested.

### INCOME.

The Statement of Accounts shows that the total receipts during 1918 were as follows:—

| | £ | s. | d. |
|---|---|---|---|
| Dividends on Investments .. | 233 | 11 | 0 |
| Interest .. .. .. | 2 | 8 | 5 |
| Annual Subscriptions .. | 120 | 5 | 6 |
| Donations of £5 and over .. | 115 | 8 | 4 |
| Donations under £5 .. .. | 23 | 10 | 0 |
| | £495 | 3 | 3 |

The accumulated unexpended Income now amounts to £1,248 19s. 9d., of which £825 15s. 9d. is invested.

### SUBSCRIBERS AND DONORS IN 1918.

#### ANNUAL SUBSCRIBERS.

H. Alabaster
G. F. Allom
Ll. B. Atkinson
S. Beeton
L. Birks
I. Braby
S. E Britton
J. Burns
H. C. Channon
R. A. Chattock
F. W. Clements
W. C. Clinton
W. W. Cook
The Hon. E. Cozens-Hardy
I. S. Dalgleish
F. R. Davenport
B. Davies
Sir Archibald Denny, Bart.
J. Devonshire
B. M. Drake
Dr. C. V. Drysdale
Major K. Edgcumbe
S. Evershed
M. Farrer
E. Garcke
F. Gill
Sir R. T. Glazebrook, C.B., D.Sc., F.R.S.
G. F. C. Gordon
F. E. Gripper
C. W. Gwyther
H. T. Harrison
C. C. Hawkins, M.A.
W. C. C. Hawtayne
K. Hedges
D. Henriques
J. S. Highfield
H. Hirst
H. C. Holroyd
S. Insull
E. S. Jacob
Dr. G. Kapp
Major A. C. Kelly
W. T. Kerr
J. E. Kingsbury
H. W. Kolle
Major A. E. Levin
J. R. P. Lunn
Sir Henry Mance, C.I.E.
W. Mead
J. W. Meares
S. W. Melsom
L. B. Miller
W. M. Mordey
W. M. Morrison
W. C. Mountain
A. J. Newman
Col. Sir A. M. J. Ogilvie, K.B.E., C.B., V.D.
C. Oliver
Lieut.-Col. W. A. J. O'Meara, C.M.G.
E. Parry
The Hon. Sir C. A. Parsons, K.C.B., F.R.S.
W. H. Patchell
C. C. Paterson, O.B.E.
F. G. Payne, D.S.O.
A. H. Preece
W. Ll. Preece
N. Prentice
H. F. Proctor
G. S. Ram
W. R. Rawlings
Major T. Rich, O.B.E.
R. Robertson, B.Sc.
S. R. Roget, B.A.
P. Rosling

ANNUAL SUBSCRIBERS—*continued.*

ANNUAL SUBSCRIBERS—*continued.*

S. A. Russell
S. G. C. Russell
W. H. Scott
E. Seddon
S. Sharp
J. F. Shipley
A. Siemens
M. G. Simpson
H. A. Skelton
Sir John Snell
C. P. Sparks
C. Stewart, B.Sc.
A. J. Stubbs
H. W. Sullivan
W. C. P. Tapper
E. E. Tasker
W. W. Thomas
Capt. C. H. R. Thorn
J. H. Tonge
A. P. Trotter, B.A.
H. D. Wilkinson
W. B. Woodhouse
J. H. Woodward
C. H. Wordingham, C.B.E.
H. E. Yerbury

DONORS.

P. F. Allan
Ll. B. Atkinson
J. F. Avila
A. H. Bate
F. H. Broomfield
J. D. Dallas
R. De Hollanda
The Diesel Engine Users' Association
The Disabled Soldiers' and Sailors' Fund
L. H. Euler
Major R. Grierson
J. S. Hasdell
Messrs. W. T. Henley's Telegraph Works Co., Ltd.
The Institution of Railway Signal Engineers
H. D. Kemp
H. F. A. Kinder
W. E. Lane
W. Lang
F. W. Main
E. Manville
C. H. Merz
H. Parry
H. A. Ratcliff
S. Simpson
Dr. S. P. Smith
A. L. Stanton
Major A. M. Taylor
The " Twenty-five " Club
T. C. T. Walrond
W. Young

Among the larger donations received during the year were one of £25 from Messrs. W. T. Henley's Telegraph Works Co., Ltd., one of £26 5s. from the " Twenty-five " Club, and £23 18s. 4d. from the Disabled Soldiers' and Sailors' Fund.

A special appeal for subscriptions to the Fund was made by the Committee at the end of 1918 and the following comparative figures taken from the Annual Report of the Council of the Institution (see page 331) show the response made by members up to 15th April, 1919.

| | No. of Subscribers | Amount Subscribed |
|---|---|---|
| 1919 | | |
| 1 January to 15 April .. .. | 570 | £422 os. 6d. |
| 1918 | | |
| 1 January to 15 April .. .. | 104 | £133 6s. 0d. |

The Committee of Management desire to acknowledge their indebtedness to these donors and subscribers, and they venture to urge upon members the pressing need for a generous support of the Fund. Apart from donations the Committee will be grateful for annual subscriptions even of small amounts.

## Grants.

Twenty applications for assistance were received in 1918 and the Committee, after due investigation, made grants in all the cases. Three grants were made of £25, nine of £10, one of £9 10s., one of £9, three of £8 15s., two of £7 10s., and one of £5, a total of £229 15s. for the year.

## Wilde Benevolent Fund.

The Capital Account stood on the 31st December, 1918, at £1,846 4s. 6d., the whole of which is invested and brings in an annual income of £55 17s.

The balance standing to the credit of the Income Account at the end of 1918 was £663 18s. 1d., of which £640 14s. 8d. was invested and brings in an annual income of £28 10s.

No grant was made from this Fund during the year.

## OBITUARY NOTICES.

HERBERT DUDLEY BARLOW was born in London in 1868, and received his early education at Brighton Grammar School. His natural gifts as an engineer very soon developed and in 1885 he went to Finsbury Technical College to study as an electrical engineering student under Dr. Silvanus P. Thompson; but, unfortunately, ill-health very soon checked his enthusiasm and he was compelled to abandon his college training. Under the doctor's advice, he booked a passage in a sailing ship bound for Australia. It had been arranged that he should make a complete voyage round the world, but on his arrival in Sydney he felt that the Australian climate suited him and, although he had only a few casual acquaintances as friends, he determined to make Australia his temporary home, and allowed the ship to continue its voyage without him. He was then only 17 years of age, but, with his love of adventure and unusual pluck, he never doubted the success of his undertaking. Within a short time he obtained a position as assistant manager to an electrical engineering firm in Melbourne, and then it was that his ability as an engineer became conspicuous. For five years he was gradually improving his position with this firm and at the same time gaining that fund of practical experience which, in his case, always formed so good a substitute for a more scientific training. In the following year he was appointed assistant to Professor Threlfall at Sydney University, and carried out many experiments during the 12 months that he remained in that position. It was always a regret to him that he had not been able to complete his college career, but it is doubtful whether his experience in Australia was not even more valuable to him as an essentially business man. By this time his old associations began to appeal to him. He had served his apprenticeship, and with his ever undaunted self-confidence he decided to return to his native country and set up a business of his own. In order to establish some connections here, he first went to Paisley as chief electrical engineer to Messrs. J. and P. Coats and gained considerable distinction. Three years later he went to London, and in partnership with his brother, Leonard Barlow, established the firm of Messrs. Barlow Brothers and Company. The partnership was dissolved four years later. He passed away on the 22nd July, 1919, after a long and trying illness borne with great courage and patience. Those who knew him will never forget his bright personality, his unusual pluck and perseverance in the face of the many hardships and trials that he was called upon to face. He was elected an Associate of the Institution in 1891 and a Member in 1898.

EDWIN BLAKEY died at his residence, Cwm Glas, Arthog, near Dolgelley, on the 24th July, 1918, in his sixty-ninth year, of pneumonia supervening on influenza. He was born in Halifax, and after leaving school started life in a woollen merchant's office. From the time he was 10 years old, however, he had taken a practical interest in scientific matters and had started experimenting in electricity at a very early age. He had no systematic training, but took advantage of every opportunity to extend his scientific knowledge by attending lectures and studying. He started in business on his own account when 24 years of age, and was founder of the firm of Messrs. Blakey, Emmott & Company, who were pioneers in telephone work and railway signalling. He retired from business on account of ill-health and in January 1895 went to live at Barmouth, North Wales, where he practised as a consulting engineer. During this time he acted as consultant to the Madeira Electric Lighting Company and various other concerns. He was buried at Arthog Churchyard on the banks of the Mawddach Estuary, in the heart of the mountain scenery he loved so well. He was elected an Associate of the Institution in 1879 and a Member in 1887. D. O. E.

JAMES CONNOLLY was born in London in November 1867 and died at Windermere in July 1919. He was educated at the Islington Science and Art School, and then went for a short period as assistant to a pharmacist. Later he proceeded to Milan and joined his father (the late Thomas Connolly), who introduced the manufacture of rubber and gutta-percha insulated wires into Italy, at the works of Pirelli and Casassa (now Pirelli & Company). He equipped the first cable-testing room for this firm, and for a period of 2½ years was in charge of their research and testing departments. During his engagement at Milan, he was awarded the "Green Ribbon of Merit." Returning to England, he was appointed by Messrs. Hooper's Telegraph and India Rubber Works to take charge of their testing department, in which capacity he carried out tests on many of the submarine cables manufactured by the firm. He subsequently resigned this appointment and rejoined his father in the firm of Messrs. Shaw & Connolly, who had established a cable factory at Manchester, and he remained with the firm after its amalgamation with the Okonite Company of Passaic, N.J. During his engagement with this Company he spent a considerable time at the factory in America, exchanging views with the principals in regard to British and American practice in the manufacture of insulated wires and cables. Shortly after his return to England the firm of Messrs. Connolly Brothers, Ltd., was established, of which he was a Governing Director up to his death. With the advent of the magneto industry, his long and varied experience, both technically and practically, led him to anticipate an insulated wire other than silk

and cotton as an insulating medium. His research work in this direction was the means of producing a satisfactory dielectric in which the residue of stearine wax is transformed into an enamel of high insulating and pressure-resisting properties. He travelled extensively in practically all the European countries, the United States of America and Canada, and, in addition to his scientific attainments, was a very fluent linguist, frequently giving lectures in the French, Italian, and German languages on scientific and other subjects. He was a Past President of the Cable Makers' Association, and he was associated with several of the Committees on the Standardization of Wires and Cables. He was elected a Member of the Institution in 1900.

Sir WILLIAM CROOKES, O.M., F.R.S., was born on the 17th June, 1832, and died on the 14th April, 1919. He was the last of a small group of scientific "amateurs" who, during the last 50 years, devoted their means, opportunities and, in fact, their lives to scientific research. Warren De la Rue, William Spottiswoode, and William Crookes, all worked on the same lines: each at his own cost equipped laboratories, conducted important researches, became successively President of the Royal Society, and each lived to be able to look back upon his past labours with the consciousness of good work done and appreciated. From the days when as a youth he worked in chemistry, photography, and astronomy, until his death Sir William Crookes had before him the pursuit of science as his main object, and this was coupled with a determination that no failure could thwart. The writer cannot recall a single instance when failure or mishap produced anything beyond a determination to try again—attention to the minutest detail characterized all Sir William's work. The discovery of the element Thallium in 1862 and the laborious determination of its atomic weight was his first marked success, and from that time onward his work was a natural sequence of connected events. So that he might carry out the determination of the atomic weight of thallium to very great accuracy he had constructed a vacuum chamber to hold his balance, and when using this he was struck by the erratic behaviour of the balance when in a vacuum. This led to his researches on "Repulsion resulting from Radiation," and the ultimate invention of the so-called radiometer or light mill, an instrument familiar enough to everyone now, but only the writer knows the magnitude of the work and the hundreds of experiments that enabled the truth of its action to be evolved from the mass of fanciful speculation that followed the first observation of such novel motions. It was about this period that Sir William has related a conversation that he had with Lord Kelvin, then Sir William Thomson, which ended in the latter's recommendation to "try electricity"; the trying of electricity led directly to those beautiful researches in "Radiant Matter" that will ever be associated with the name of Crookes. The lecture with the above title delivered at Sheffield in 1879 created a sensation in the scientific world, and was remarkable both for the beauty of the experiments shown and for the boldness of the speculations which accompanied them. During the work on radiant matter the spectroscope was frequently employed to examine the brilliant radiations emitted by various solid substances under bombardment with cathode rays, and the occasional appearance of a bright citron-coloured band gave rise to a long research published under the title of "Radiant Matter Spectroscopy." This research extended from 1883 until a few years ago, and led to some very advanced and far-reaching reasoning upon the constitution of matter and the genesis of the elements. At the British Association meeting in Birmingham in 1886 Sir William enlarged upon the difficulties of separating the various members of the "rare earth" elements, and in speculating upon the ultimate constitution of matter proposed the name "Protyle" for the "something that existed anterior to our elements." His investigations in radiant matter spectroscopy were at first wholly connected with the visible spectrum, entailing laborious observation on account of the faintness of the light. This suggested the hope that photography might be made to record the spectra with also the possibility that invisible bands in the ultra-violet region might be revealed. For this purpose a quartz spectrograph was constructed and became the starting-point of spectroscopic investigations that continued from about the year 1888 and were in full swing at the time of his death. The first results of work with the quartz spectrograph was the discovery that the discontinuous phosphorescent spectrum extended far into the ultra-violet. Many bands showing details of construction exactly similar to those in the visible portion of the spectrum were observed; one particularly fine group of bands was always found to accompany the fractions of the yttria earth series having an atomic weight of about 117, and work in chemistry aided with the spectrograph was concentrated in order to isolate the material. This was partly successful and caused Sir William (perhaps a little prematurely) to announce the discovery of a new element of the rare earth group to which he gave the name Victorium. This work was unfortunately never completed, and the matter remains for some future investigator to grapple with.

The success with the first spectrograph, with two quartz prisms, led to the construction of a much larger instrument with a train of five prisms, and this apparatus, with a measuring micrometer constructed at the same time, has been used to record the arc and spark spectra of a great number of elements and some thousands of photographs have accumulated.

In this brief outline of the labours of Sir William Crookes from the inside, a detailed account is not given of all the work of the past 50 years. This has been published elsewhere; the number of "papers" amounts to some hundreds, for Sir William was an indefatigable worker. Except for a brief holiday in the summer, week in, week out, he was constantly in his laboratory. It was one of his favourite sayings that a man should always have a little more to do than he could possibly accomplish, and this became true in his own case, for death came before he had ceased working, and he has left many things undone. His last paper on "The Arc

Spectrum of Scandium" has just been published in the *Proceedings of the Royal Society*. As the end approached, bringing much pain, there was never a murmur of complaint, and he remained bright and kindly until the last. He continued to come down into his study until within the last few days, and then like a tired child laid down and passed quietly away. His list of honours and distinctions was a large one, but while keenly appreciating the public recognition of his labours he cared very little for insignia, which were mostly stowed away in a drawer in the corner of his study and, except for the Order of Merit bestowed upon him in 1910, were rarely brought into the light. He was elected a Member of the Institution in 1881 and was President in 1891. J. H. G.

JAMES FOYELL L. CROSLAND was born in Leeds on the 9th March, 1840, and served his apprenticeship in the locomotive works of the Manchester, Sheffield and Lincolnshire Railway. On completing his apprenticeship he practised as consulting engineer in collaboration with his father, who had many patents relating to fuel economy, superheated and high-pressure steam, and compound and triple-expansion engines; and prior to 1863 he advocated the triple-expansion engine with steam pressures of 150 to 200 lb. per square inch. In 1864 he joined the Boiler Assurance Company, now the Vulcan Boiler and General Insurance Company, Ltd., and was appointed Chief Engineer of the Company in 1888. He retired from that position in 1912. He was elected a Member of the Institution in 1900.

JOHN HUBERT DAVIES was born at Blakeney, Gloucester, in 1858, and was left fatherless when 14 years of age. After receiving his early education at a private school in the South of England, he went for 10 years into a merchant's office where he received a sound commercial training. During the latter part of this period he studied mechanics, physics, and chemistry in his spare time, and in 1882 he decided to give the whole of his time to these subjects. He formed a small workshop and laboratory for electrical and chemical research, devoting his attention mainly to the production of a voltaic cell in which electricity could be produced direct from coal. Lack of funds, however, prevented his continuation of the work, and in 1883 he obtained an appointment in the drawing office of Messrs. Woodhouse and Rawson of London, remaining with the firm until 1887, when he left in order to develop certain inventions which he patented. He returned to the firm a year later as chief draughtsman and electrician. In 1889 he accepted an engagement to proceed to South Africa to supervise the erection of electric light plants for three gold mines on the Rand, and he was retained as consulting electrical engineer to Messrs. Howard, Farrar and Company. Two years later he started in Johannesburg on his own account as an electrical and mechanical engineer, establishing the business of Messrs. Hubert Davies and Company, and he was associated from that time with most of the pioneer electric lighting and power plants in South Africa, either in a consulting capacity or as contractor. He also interested himself in nitrate discoveries. He acted as consulting engineer to —among other firms—the Johannesburg Lighting Company, Pretoria Lighting Company, East London Municipality and many gold-mining companies. During 1895 and 1896 he built and equipped an electric surface haulage at the new Modderfontein gold mines. About this time he took into partnership Mr. William Spain, and the firm was carried on under the title of Messrs. Hubert Davies and Spain until 1907. During this period a great amount of electrical plant was installed on the Reef and elsewhere. In 1907 the partnership was dissolved and the firm again became Messrs. Hubert Davies and Company, with Mr. Davies as sole partner. This arrangement continued until 1918, when he converted the business into a private limited liability company, with the title of Messrs. Hubert Davies and Company, Limited. He died at Cape Town on the 12th December, 1918. By his death the electrical profession loses one of the few remaining pioneer electrical engineers in South Africa, and his lifelong benevolence will make his memory endure in the hearts of all who have had the privilege of his friendship. He was elected a Member of the Institution in 1890 and served as Local Honorary Secretary and Treasurer for the Transvaal from 1899 until his death. He was also a Foundation Member of the South African Association of Engineers and Architects, and read the first paper submitted at their first meeting held in Johannesburg on 27th June, 1892, entitled "Electrical Transmission of Power."

VYVYAN OSWALD DAVIS was born in London in 1885, and, after having received his early education at St. Augustine's College, Ramsgate, and at Wimbledon College, became a pupil at the City and Guilds Engineering College, South Kensington, where he was awarded the Mitchell Scholarship. On the completion of his studies at the last College, he entered the works of Messrs. C. A. Parsons and Company at Newcastle-upon-Tyne, where he remained for a period of five years, for the greater part of this time having charge of all electrical testing. In 1909 he entered the service of the A.E.G. as sales manager in this country, but left it three years later to join the staff of the British Thomson-Houston Company at Rugby. After a short stay there he was appointed by this firm as manager of their Newcastle and Middlesbrough offices, a position which he retained until the beginning of the War, when he received a commission in the Royal Engineers. He proceeded to France in 1915, and after a year's service in the Ypres sector was invalided home. On the termination of a brief period of home service, he was released from the Army to resume his employment at Newcastle. He died on the 6th November, 1918, of pneumonia following upon influenza, his heart having become affected as the result of "gassing" while on active service. He was elected a Student of the Institution in 1903, became an Associate Member in 1911, and a Member in February 1918.

GEORGE CAREY FOSTER, LL.D., D.Sc., F.R.S., died in his eighty-fourth year on the 9th February, 1919. He was the only son of George Foster, a calico printer and

a Justice of the Peace for Lancashire and the West Riding of Yorkshire. He was born at Sabden in Lancashire in October 1835. He was educated at private schools and University College, London, where he was attracted to chemistry. He took an Honours degree and a prize in chemistry in 1855, and acted for some years as assistant to Professor Williamson. After 1858 he travelled on the Continent, and spent some years in study in Ghent, Heidelberg, and Paris. While he studied chemistry he paid more and more attention to physics, and especially to thermodynamics and electricity. His elaborate article on "Heat," published in 1863 in Watts' "Dictionary of Chemistry," was a complete treatise which guided students in research for many years. Guidance of that kind is not now to be had. In 1862 he became Professor of Natural Philosophy in the Andersonian University, Glasgow, and in 1865 he became Professor of Experimental Physics in University College, London. On the retirement of Professor Hirst in 1867 from the chair of Mathematical Physics, the two chairs were combined into the single chair of Physics, which became in 1888 the Quain chair, under the endowment of Sir Richard Quain; this was held by Dr. Foster till 1898, when he retired. In 1900 the office of Principal of the College was instituted, and Dr. Foster filled it during the four critical years which followed. He remained a member of the College Committee till 1916, when he retired on account of deafness. He was a strong supporter of the movement for the admission of women to University teaching, and took a leading part in the pioneer work of his College towards the fulfilment of this aim. Of late years he lived a rather retired life on a pretty country estate at Rickmansworth. He acted as J.P. for Hertfordshire and as manager of Mill End Schools, and took a lively interest in politics. After the death of his wife in 1917 he took less interest in public affairs, but even within two weeks of his death he busied himself still as an editor of the *Philosophical Magazine*. At the end of January he had a slight attack of congestion of the lungs, his heart gradually became weaker during 10 days, and he died in the presence of his children. "He was a very modest and retiring man who in no sense courted popularity, but his sterling character assured him of the high esteem and regard of all those who had the privilege of knowing him." These are the words of a man who knew him in politics, in his citizen duties.

The experimental methods introduced by him, especially in electricity, have been generally adopted in all laboratories in the world; the Carey Foster bridge is still in use as the best method of measuring small resistances. Sir William Thomson (Lord Kelvin) allowed one or two students to do experimental work, and so did Professor Foster; but Foster was the first to establish that kind of regular laboratory work for students which is now to be found in all colleges. Sir Oliver Lodge, one of his old students, writing in the *Philosophical Magazine*, says, "George Carey Foster was one of the most lovable of men. He was a man of remarkably sound judgment, so that his opinion, when he would give it, was always welcome: he had an instinct for discriminating between wise and foolish schemes or policies, and always lent the weight of his influence in what experience showed to be the right direction. . . . He was never a fluent lecturer; he thought too carefully over his sentences, and delivered them with a hesitancy that made him difficult to follow; yet, when taken down, his lectures were a model of cautious, exact exposition—accurate and well-formed, like his handwriting. By senior and painstaking students he was much appreciated; and, though he made no claim to encyclopædic knowledge, his acquaintance with German treatises enabled him to direct inquirers to original sources, and to stimulate a certain type of research; while his natural bent led him to encourage exact measurement. . . . He was very modest about his own work, and sometimes seemed rather surprised at the importance attached by physicists to his paper before what was then the Society of Telegraph Engineers (now the Institution of Electrical Engineers) on the 'Wheatstone Bridge.' But at the time it was written, it was a most ingenious and instructive piece of work, and displayed a number of special features which anyone less critically thorough than himself would have overlooked. Undoubtedly he therein devised the method—not at all an obvious method—for extremely accurate comparison of standards of resistance, turning the bridge into an instrument for the measurement of differences instead as previously only of ratios, and thus importantly supplementing Wheatstone's or Christie's original design. The principle of the Carey Foster bridge was also used by him for a very accurate and convenient method of plotting the equipotential lines of a current flowing between electrodes situated anywhere in a plane conducting sheet. . . . Many other things he did; but after all his desire to help senior students, and those members of the staff who came under his personal influence, was perhaps the most prominent feature of his life and the one I have most pleasure in remembering; his house in Hilldrop-road, Camden Town, was the centre of simple and kindly hospitality. Not at all likely to be deceived by mere plausibility, and of a very critical and shy disposition, he formed his judgment of men, and when it was favourable nothing that he could do to help them was too great a call upon his time. . . . Long and well did Carey Foster serve the *Philosophical Magazine*, and he must have acted as referee for an immense number of papers. Of Dr. William Francis, senior, he was an intimate friend, and gave him the benefit of counsel and support through difficult negotiations at a time when the policy of the conductors of the *Magazine* was passing through what might have been a revolutionary period. He regarded the *Magazine* as one of the bulwarks of serious physics in this country, and exerted himself to preserve it practically in its ancient form. He also took a leading part in the formation of the Physical Society of London: he and Professor Guthrie together were in my opinion its real founders. . . . Through the period of the seventies of last century it is not too much to say that Carey Foster was the leader of physics in London; and a wiser, more cautious and yet earnest and indefatigable man could not readily have been found."

In 1892 a special building for Research in Experimental Physics was erected at the College and named after him, to commemorate the fact that he was the pioneer in giving students laboratory work as a part of the curriculum. He was a fellow of the University, but he was more particularly a fellow of the College, of which he was a loyal son. Education, untrammelled by extraneous considerations, could not be obtained elsewhere in the days when the College was founded. In his own words, he looked upon the College "not only as an important place of education, but as an important expression of a most remarkable intellectual movement"—a movement which stood "for free inquiry and effort towards improvement, intellectual and social." He was anxious that the University of London should become something more than a mere examining body, and in pursuit of this idea he supported the movement that led to the incorporation of the College with the University. Some account of his work in this connection will be found in a notice by Dr. A. H. Fison in the *Transactions of the Chemical Society*, 1919, vol. 115, in which will also be found an account of his early scientific papers, which are all related to chemical subjects. Every electrical engineer ought to study the volume containing all the Reprinted Reports of the British Association Committee on Electrical Standards [Cambridge, The University Press, 1913] for 50 years, from 1862 to 1912. He will there see how the greatest scientific men worked, year after year, to place electrical engineering on a firm foundation. Lord Kelvin, Wheatstone, Matthiessen, Jenkin, Siemens, Maxwell, Joule, Carey Foster, Latimer Clark, Hockin, Ayrton, Lord Rayleigh, Dr. Muirhead, Hopkinson, Schuster, Glazebrook, and Viriamu Jones, these among many others are names that deserve honour. Much of the work done may be understood from Foster's article "Electricity," in Watts' Dictionary. In 1881 the B.A. committee published Carey Foster's paper, "An Account of Preliminary Experiments for the Determination of the Electro-Magnetic unit of Resistance in Absolute Measure." The committee had in 1863 adopted the method of revolving a large flat closed coil of insulated copper wire about a vertical diameter so that the horizontal component of the earth's magnetic field produced an electromotive force and therefore a current in the coil, whose amonnt was measured by the deflection of a magnetic needle suspended at the centre of the coil. The circuit was completed only for a short interval when the plane of the coil was nearly in the magnetic meridian. In Carey Foster's method the circuit of the rotating coil was closed for a much longer period; the standard coil was distinct; its resistance was measured when it formed part of a fixed and independent circuit; it might be of copper or any other material, and its temperature could be kept constant and measured with accuracy. The correction for self-induction of the revolving coil was reduced, but unfortunately it was necessary to take its capacity into account. The results were not good enough to satisfy Foster, especially as about that time Lord Rayleigh and Professor Schuster, using the original apparatus of 1863 and adopting new precautions, obtained results which they published in 1882, results whose values were and are now accepted as close approximations to the truth. From 1897 onwards Professor Viriamu Jones and Professor Ayrton, using an apparatus described by Lorenz, with improvements suggested by experience, obtained the results which are at present accepted and on which the governments of the world now base their definitions of commercial electrical units. Before the Physical Society of London, Foster published in 1884 a paper "On the Difference of Potential required to give Sparks in Air," and in 1886, "On a Method of Determining Coefficients of Mutual Induction." This is the standard method now used in laboratories. In later years he published a textbook on Electricity in collaboration with Professor Porter.

He became a member of the British Association in 1857, and took an active part in its work till late in life. He was a member of many of its Research Committees, among which were that already mentioned on Electrical Standards; those on the Selection and Nomenclature of Dynamical and Electrical Units; the State of Knowledge of Spectrum Analysis and Electrolysis. He was President of Section A in 1877. He was General Treasurer of the Association from 1888 to 1904. Of the Physical Society of London he was not only one of the founders in 1873 but he was President in 1887 and 1888. He helped to found the Society of Telegraph Engineers (now the Institution of Electrical Engineers), was its President in 1880 and 1881, and was elected an Honorary Member in 1916. He became a Fellow of the Royal Society in 1869, acting as a Vice-President from 1891 to 1893 and also from 1901 to 1903. He was an active member of the Kew Committee. He received the honorary degrees of LL.D. from Glasgow and D.Sc. from Manchester. He was an honorary member of the Jewish Historical Society and of the American Philosophical Society. Readers will find much to interest them in the above-mentioned obituary notice in the *Transactions of the Chemical Society* by Dr. Fison, the pupil, assistant and friend of Carey Foster. They will find interesting details in regard to the start and growth of his laboratory work until its consummation in the new building, the faithfulness of his dealing with students, and other matters which one lingers over with pleasure. Dr. Fison publishes a page of extracts from a few letters whose whole-hearted fun may be a revelation to many readers. For myself I wish we had a hundred such pages of kindly fun. Dr. Fison says: "The private life of Carey Foster was one of quiet beauty. His transparent honesty and high regard for truth earned him the respect of his friends, whilst his unvarying kindness and courtesy won their affection."

In 1868 he married Mary Anne Frances, daughter of Andrew Muir, of Greenock. They had four sons and four daughters, all of whom are still living.

Carey Foster had many distinguished pupils. I have quoted the words of two of them. I can only add that all younger workers in physics were grateful to him for kind encouragement. We admired him for the soundness of his own work and his great knowledge of what other people had done, but above all we admired him as a thoroughly good man J. P.

ICHISUKE FUJIOKA, fourth class of the Imperial Japanese Order of the Sacred Treasure, died on the 5th March, 1918, at his residence in Tokio, after many years' illness of paralysis. He was born in March 1857 at Iwakuni, and graduated in electrical engineering at the Imperial Japanese College of Engineering in May 1881. He at once obtained an appointment as assistant professor at the same college, and was promoted to the professorship in 1884. After five years' service he retired, and was appointed chief engineer of the Tokio Electric Light Company, the first electric light undertaking in Japan. Later he became one of the founders of the Tokio Electric Railway Company, the forerunner of the present municipal tramway system. In addition, he was interested in the manufacture of incandescent lamps and very early established the Tokio Electric Company, later devoting much of his time to the work of that company, of which he was president until his death. He was elected a Foreign Member of the Institution in 1884 and a Member in 1911, and he served as Local Honorary Secretary and Treasurer for Japan from 1892 to 1916.

I. M.

BERTRAM HOPKINSON, C.M.G., F.R.S., Lieut.-Colonel R.A.F., was killed while flying in discharge of his duties as Deputy Controller of the Technical Department of the Royal Air Force on the 26th August, 1918. An authoritative and comprehensive account of Professor Hopkinson's life and work by Sir Alfred Ewing has been published recently in the *Proceedings of the Royal Society* (Series A, vol. 95, p. xxvi), consequently it is considered desirable that this notice should deal more particularly with Hopkinson's work in electrical engineering and his activities during the last four years. A brief sketch of his life is, however, necessary. He was born in Birmingham 11th January, 1874, his father being John Hopkinson, F.R.S., the first and greatest of electrical engineers and some time President of the Institution. After a brilliant career at St. Paul's School and Trinity College, Cambridge, ending in a first class in Part II of the Mathematical Tripos, Hopkinson was called to the Bar in 1897 and began to practise. In August 1898 his father, with three of his children, was killed in climbing the Petite Dent de Veisivi. Bertram Hopkinson left the bar to carry on his father's consulting practice with Messrs. Charles Hopkinson & E. Talbot. This was a bold step, but Hopkinson had absorbed a good deal of engineering from his father, and he continued in practice till 1903, when he became Professor of "Mechanism and Applied Mechanics" in the University of Cambridge. In the same year he married the eldest daughter of Mr. Alexander Siemens.

Practical patriotism is hereditary in the Hopkinson family; John Hopkinson was the first colonel of the Corps of Electrical Engineers, and his son, with the rank of Major (Territorial), commanded the Engineer Section of the Cambridge O.T.C. When the war fell upon us Hopkinson at once relinquished all other activities. He was instructor at Chatham, later was engaged on some wireless work at the Admiralty, was a member of various technical committees as they were formed, devised a means of protecting ships against torpedo attack, and finally settled down to the Flying Corps, at first in connection with bombs and bomb sights. The power of his personality and attainments was such that he rose from one position to another till at the time of his death he was Deputy Controller of the Technical side of the Air Force Equipment Branch, and the most influential man in all that concerned the development of air fighting on the Equipment and Experimental side. He considered it his duty to learn to fly, though he was over 40 years old, and in this no doubt he was right. He used to claim that he could get about so much more quickly by flying that he could accomplish two or three times as much work as was possible without it, and in addition that it gave him a better standing with his staff. In his youth Hopkinson had been a keen small-boat sailor, and he looked upon flying as a sort of improved boat-sailing. He was very fond of it, and soon ceased to be satisfied with what he called "a family bus." On the morning of the 26th August, 1918, the weather was threatening and the clouds low, but Hopkinson was anxious to get to London. He started in a Bristol Fighter from Martlesham Heath, but as he approached London the clouds got lower and it is supposed that he lost control in descending through them, and had not height enough to recover; he fell near Hainault Farm, and must have been killed instantly.

Hopkinson's first paper was mathematical and dealt with discontinuous fluid motion, but on joining his father's firm his attention was naturally directed to such matters as came before him professionally. Among the works in which the firm was engaged were:—Tramways at Leeds, Liverpool, Newcastle-on-Tyne, electric lighting of St. Helen's, electricity supply at Crewe, Sale, Faversham, and Ealing. In the work on the Newcastle tramways and the extension of the tramways at Leeds, Hopkinson found scope for all his energy. There were still some tramway problems to be tackled at the opening of the twentieth century, and Hopkinson experimented on tensions in overhead wires, earth leakage currents and their corrosion effects, and similar matters. A paper on electric tramways by the members of the firm in which these matters were dealt with was read at the Institution of Civil Engineers in November 1902, and gave rise to an interesting discussion. Hopkinson was also very interested in the subject of the hunting of alternating-current motors, and read a paper on the subject (*Proceedings of the Royal Society*, 18th June, 1903). His mathematics were still at his finger ends, and the subject suited his powers—like his father he preferred analytical methods—and this makes the paper unattractive to those (and they are in the majority) who are not facile mathematicians. However, this was followed by a paper on the same subject to the British Association (*Electrician*, 1903, vol. 51, p. 886) in which a more readable account of the matter is given, and this paper is perhaps the clearest statement of a rather complicated subject which is to be found anywhere. The work is interesting as the effect of resonance appears as a particular case only in a general treatment. The writer at all events has used it for many years whenever the subject cropped up.

Hopkinson's active life at Cambridge extended from 1903 till the outbreak of the war, and of course his main work was in connection with the duties of his chair, but an immense amount of original work was carried out. This was on four main lines, gas engines, measurement of shaft horse-power, properties of steel —especially magnetic properties—and researches on the dynamical aspect of explosions. The researches on gas engines are extensive, and taken together cover most of the ground. The investigation is very thorough, from both the physical and engineering point of view; of particular interest was the discovery of the great influence of radiation on heat losses in the cylinder and the explanation of the fact—too familiar to all acquainted with gas engines—that if pre-ignition once occurs the tendency is for it to get worse rather than better. The measurement of shaft horse-power led to a successful invention of a new horse-power indicator in corroboration with Mr. L. G. P. Thring. It was, however, in the work on explosions that Hopkinson's characteristic powers may be said to be fully exhibited. The work is described in the *Transactions of the Royal Society*, Series A, vol. 213, p. 437, and in a lecture at the Royal Institution, 26th January, 1912, under the title "The pressure of a blow" (see also "The Effects of the Detonation of Guncotton": *Proceedings of the North-East Coast Institution of Engineers and Shipbuilders*, 1913–1914, vol. 30). Hopkinson's attention was no doubt attracted to the subject by the fine work "On the Longitudinal Impact of metal rods with rounded ends" (*Cambridge Philosophical Society*, 1907, vol. 14, p. 257) by Mr. J. E. Sears—which itself was suggested by Hopkinson's previous work on the "Momentary stresses in metals" (*Proceedings of the Royal Society*, vol. 74). Of this work it must suffice to say that measurement of the momentum conferred on bodies by explosions taking place near them have of course often been measured and the time integral of the forces thus ascertained. The separation of the time from the pressure element, however, in such a manner that both could be inferred simultaneously had not hitherto been accomplished directly. The method invented by Hopkinson consisted in firing a charge of explosive near to one end of a steel bar suspended so that it lay horizontal; at the remote end of the bar similar pieces of steel of various lengths were held very lightly by magnetic forces. Under certain circumstances the free "pieces" flew off as a result of explosion and were caught in a ballistic pendulum. From a knowledge of the velocity of sound in the steel used and measurements of the momenta acquired both by the bar and the end piece, at all events the maximum pressure and duration of pressure at the face near the explosion can be deduced. It is obvious that a new and valuable method has been invented for comparing the effects of explosive charges, for instance, and full advantage of this was taken during the war

Important and original as was the work done at Cambridge, it really amounted only to an apprenticeship for what was to follow during the war. Hopkinson's services to the country are not to be associated with any particular invention. They lay in his contribution to the building up of the greatest and most formidable air power in the world. In the struggle for aerial supremacy no one factor was more important than keeping the lead in technical equipment and air fighting tactics. This of course rested ultimately on experimental work, and it was the general organization and direction of this work which constituted Hopkinson's contributions to his country's victory. When he was first connected with the Air Force, experimental and training work were carried on together at one or two air stations, but by the establishment of the Experimental Station at Orfordness Hopkinson was able to bring a concentrated effort to bear on experiment unhampered by the exigencies of training. For this no one could have been more fitted either by nature or by training. Tall, of a commanding presence, with immense physical strength and energy, with ripe engineering experience and great originality of mind, of a perfect and unruffled kindliness and serenity, he commanded respect and confidence in all those who worked with him. His character was in keeping with the external attributes of manliness, without a trace of self-seeking, without a thought that was not directed to the country's good, obviously ready to make any personal sacrifice, and as obviously of a strong, independent, and fearless personality, he was born to command, and command he did. The war has brought to light a great reserve of nobility and talent in the nation, but no more conspicuous example is to be found than in the life and work of Bertram Hopkinson.

He was elected an Associate of the Institution in 1897 and a Member in 1902, and served on the Council from 1914 to 1916. R. T.

EDWARD J. HOUGHTON was born in 1844 and was educated privately in London. He entered the service of the London, Brighton and South Coast Railway in his fifteenth year, and occupied successively several junior positions in the telegraph department under Mr. E. G. Bartholomew, F.R.S., at that time the Telegraph Engineer of the Company. When Mr. Bartholomew left the Brighton Railway he was succeeded by Mr. Cripps, and Mr. Houghton was appointed his Chief Assistant. On the death of Mr. Cripps in 1875 Mr. Houghton was appointed Chief Telegraph and Electrical Engineer of the Railway, which position he held until the time of his retirement. His name was known in the railway world principally as the pioneer of the lighting of railway trains by electricity. In 1881 he fitted up with electric lighting a Pullman car train which ran between London and Brighton. It is believed by the writer that this was the first attempt to light a train by electricity, and it was considered a sufficiently remarkable event to form the subject of a leading article in the *Daily Telegraph* in October 1881. The lighting for this train was supplied in the first case from accumulators only, which had to be charged each night during the time the train was shunted in the sidings. A little later, however, Mr. Houghton designed apparatus whereby the accumulators were charged by a dynamo placed in the guard's van and driven by belting from the axle. This apparatus, with various improvements introduced from time to time, was the

subject of some 14 patents taken out between the years 1885 and 1892. The working was found so satisfactory that its use was considerably extended, until eventually nearly 400 coaches were equipped with the apparatus on the Brighton Railway. A number of trains, also, were similarly equipped on other railways both in this country and in the colonies. There are still several trains, including the Royal train, running on the Brighton Railway fitted with Mr. Houghton's apparatus. In addition to his work with train-lighting apparatus, Mr. Houghton was the inventor and patentee of a number of appliances in connection with railway telegraph and signalling apparatus. He was one of the first to experiment with track circuiting for controlling the signals and block apparatus. In the early eighties a section of line on the Brighton Railway was track-circuited and fitted with apparatus for locking the signals and controlling the block instruments, and was in regular use for some time. It was eventually abandoned, mainly owing to the fact that at that time a large proportion of the wheels of vehicles were unbonded and consequently failed to short-circuit the rails. During the time Mr. Houghton was with the Brighton Railway he was responsible for an extensive development of the electric lock and block system of train signalling and the installation of a number of electric lighting and power plants at various stations and depots on the system. During the last year of his service with the Railway the South London Line was equipped for electric traction. He retired from the service of the Railway in September 1909, and passed away at his residence in Croydon on the 16th December, 1918, after a short illness. He was elected a Member of the Institution in 1876. R. H. H.

KARL KONOW VON KROGH lost his life in his forty-first year by an accident on the 27th September, 1917, in the works of the Allmänna Svenska Elektriska Aktiebolaget, Västeras, Sweden. He was born in Kongsvinger, Norway, and received his electrical education at the technical university at Darmstadt, which he left in 1899. For some time, both before and after passing his examinations, he held the post of assistant in the electrotechnics department of the university. After leaving the university he was employed for some time by Messrs. Siemens & Halske of Charlottenburg, and later by the Allgemeine Elektricitäts-Gesellschaft, Berlin, as head of the experimental laboratory, subsequently becoming chief engineer in the transformer department of that firm. In the year 1904 he obtained an appointment with the British Westinghouse Electric and Manufacturing Company as head of the transformer department. Five years later he returned to Norway, and joined the consulting engineering business of J. P. Nissen, which later became Messrs. Nissen & von Krogh. He was well known in his own country not only as an electrical engineer but also for his personal qualities and noble character. He was elected an Associate Member of the Institution in 1905, and became a Member in 1910. T. N.-S.

FREDERICK JAMES LAUNCHBURY was born on the 5th September, 1884, and died on the 27th March, 1919. He was educated at Edgbaston School, Birmingham, and after serving a four years' apprenticeship as a mechanical engineer he was appointed assistant on the testing staff of Messrs. Chamberlain and Hookham. A year later he obtained an appointment as shift engineer in the Scottish House-to-House Electricity Company, Ltd., and subsequently became substation superintendent in charge of one rotary and several static substations. In November 1906 he entered the service of the Coatbridge and Airdrie Electric Supply Company, Ltd., as chief assistant and mains superintendent. In 1909 he became Resident Engineer to the Company and was responsible for the engineering side of the Company's business. He resigned in April 1918 on obtaining an appointment with the Greaves Etchells Company of Sheffield. He was elected an Associate Member of the Institution in 1910 and a Member in 1916.

WILFRID JAMES LINEHAM was born at Leeds on the 17th December, 1858, and served his apprenticeship with Messrs. John Fowler and Company of that city. He remained with that firm altogether for about 10 years, during part of which period he was engaged in the design of ploughing, traction, and stationary engines. Subsequently he was for three years chief designer with Messrs. R. & W. Hawthorn, Leslie and Company, Newcastle-on-Tyne, and for five years with Sir W. G. Armstrong, Mitchell & Company, Elswick. Concurrently with his work as a designer he devoted considerable attention to teaching. For two years he conducted evening classes in Leeds, Dewsbury, Wakefield, etc., and later was principal lecturer in engineering at the School of Science and Art (now the Rutherford College), Newcastle-on-Tyne. He was then appointed Head of the Engineering Department at Goldsmiths' Technical Institute, New Cross, this department comprising mechanical engineering, electrical engineering, civil engineering, building trades and architecture. When the Institute became the Goldsmiths' College of London University he continued to serve as Head of the Engineering Department, a position which he held until his death. He was an examiner of London University in engineering subjects, and was also for some time an examiner to the City and Guilds of London Institute and to the Civil Service Commission. He was the author of a "Textbook of Mechanical Engineering" which has become a standard work. At the outbreak of war he was in Bavaria, and after much hardship managed to get back to England. In 1915, with a staff composed of his own assistants in the Engineering Department of Goldsmiths' College and a number of London County Council manual training instructors, he attacked with considerable success the problem of manufacturing gauges for fuses and shells, for which there was a heavy demand at the time by the then newly-formed Ministry of Munitions. Later he undertook the manufacture of screw-pitch measuring machines to designs supplied by the National Physical Laboratory, and 20 of these machines, capable of giving screw-pitch measurements to 0·00001 inch, were made at Goldsmiths' College. Early in 1918, owing to the great demand for aeroplanes and machine

guns, he was asked to cease the manufacture of the simpler form of gauges and to increase the output of position gauges, and to undertake the manufacture of screw gauges, directing his whole energy to these two types. In November 1918 his physician sent him home to rest from labour, physical and mental, but the anxieties of the last four years had been too much for him and he died suddenly on the 17th April, 1919. His versatility was very remarkable, for, in addition to his great attainments in science, he was a clever musician and a painter of such ability that his works were frequently to be seen on the walls of the Royal Academy. He was elected a Member of the Institution in 1902.

The Rt. Hon. Sir JOHN HAY ATHOLE MACDONALD, P.C., K.C., G.C.B., LL.D., F.R.S., was born in 1836 and received his education at the Edinburgh Academy and at the Universities of Edinburgh and Basle. In 1859 he was enrolled as an Advocate and during his early years of practice at the Bar published a useful work on Criminal Law and Procedure. Always strongly conservative in politics his opportunity came with Disraeli's return to power in 1874, and he subsequently filled the important offices of Solicitor-General and Lord Advocate (1885). In 1887 he carried the Act for the Amendment of Criminal Procedure in Scotland, an important measure on which his fame as a Lord Advocate chiefly rests. In 1888 he succeeded Lord Moncrieff as one of the Lords of Session, and his political career automatically came to an end. As Lord Justice-Clerk he assumed the title of Lord Kingsburgh, by which name he was known till 1915, when on retirement from his judicial duties he became familiarly known again as Sir John Macdonald. He was a man of many interests, two of which call for special notice. He was keenly interested in all that pertains to the art of war, being himself not merely an enthusiastic volunteer but one who by his suggestions and writings had an important influence on the methods of training in the regular Army. For many years he captained the Scottish Twenty Team in the National Challenge Trophy Competition, and was also Captain of the British Rifle Team which took part in an international match at the Philadelphia Centenary Exhibition. He filled the highest offices in the Volunteer Service, received the Volunteer Decoration in 1892, and on the occasion of Queen Victoria's Diamond Jubilee was awarded Commemoration Medals as Adjutant-General of the Royal Company of Archers and as Brigadier-General in command of the troops on duty at the Royal Procession. He was the author of numerous books on drill and infantry tactics. He was also greatly interested in applied science, especially in the development of motor traction and in all things connected with the use of electrical power, and he was one of the first persons in this country to possess and to drive his own motor-car. He was President of the Scottish Automobile Club; and so convinced was he of the growing importance of the motor vehicle that he very early argued for the disuse of all tramway systems, whether cable or electrical, and for the substitution in their place of the motor omnibus. He was also one of the Vice-Presidents of the Royal Society of Edinburgh. Sir John was a delightful companion, full of human interest, with a fine humour and large repertoire of racy stories. Many of these will be found in his "Life Jottings of an Old Edinburgh Citizen" (1915), a charming example of the best type of light literature. Under the pseudonym of "Jean Jambon" (John H.A.M.) he published in the late seventies "Our Trip to Blunderland"—a book written for the amusement of his own boys and frankly modelled on the classics of Lewis Carroll. The Scottish Bench is rich in its memory of great lawyers who well know the Horatian maxim *Dulce est desipere in loco*. Sir John may not be ranked with the greatest of these; but few could show greater versatility in the multiplicity of interests and in the faculty for pure enjoyment of life. He retained his faculties in full activity to the end of his long life, having visited London on Committee work only the week before his last brief illness. He died in Edinburgh on the 9th May, 1919, on the very day on which the freedom of his native city was to have been conferred upon him. He was elected an Associate of the Institution in 1882 and a Member in 1886

JACQUES MANNE was born in 1847. He received his education at the School of Mines attached to the University of Liège, and obtained the Diploma in Engineering. In 1871 he entered the works of Monsieur G. Montefiore-Levi at Val Benôit, near Liège, and was appointed manager in 1873. In 1897 when the works were converted into a limited company under the title of "Société Anonyme des Fonderie et Trifilérie de Bronze-Phosphoreux," he became its Managing Director. He devoted attention to electrical matters and conducted numerous experiments with a view to replacing iron and steel overhead wires, which had many disadvantages, by copper wires. The discovery of phosphor-bronze wire solved the problem. The results of the researches undertaken by him, in collaboration with Monsieur Montefiore-Levi, were the subject of various papers. He also took out numerous patents relating to the improvement of workshop tools, especially wire-drawing machines, and devices for the support and jointing of phosphor-bronze conductors so as to adapt them for long-distance transmission, also lightning arresters. The works with which he was associated were among the first, in 1883, in Belgium to adopt electric lighting. An active and far-seeing business man M. Manne always took great interest in the well-being of his employees, and for their benefit he founded insurance schemes, superannuation and benevolent funds, and savings banks. He also organized courses of instruction for his employees and provided a library for them. As a Councillor for the Commune of Anderlecht, he was greatly interested in professional and technical education, and for more than 29 years was a member of the Board of Management of the Technical School of the district. A member of most of the Belgian learned societies, he was elected President of the Société Belge d'Electriciens for the year 1888–1889. Warm hearted and of sterling honesty, by nature obliging and endowed with a sound judgment, he was always

the friend of his colleagues and staff. The anxieties which were brought upon him by the War as a result of the closing of his works, and the departure of a beloved grandson who volunteered for active service at the age of 18, shortened his days and he died at Anderlecht, near Brussels, on the 30th March, 1918. He was elected a Foreign Member of the Institution in 1886, became a Member in 1911, and served as Local Honorary Secretary and Treasurer for Belgium from 1913 until his death. H. A. R.

JOSÉ FRANCISCO MARTINS-GUIMARAES was born at Campos, Rio State, on the 3rd July, 1876, of Brazilian parents. He entered the Naval Academy in 1893 as a cadet, and distinguished himself by gaining the Greenhalgh gold medal. He was promoted midshipman in 1897, lieutenant in 1899, lieutenant-captain in 1902, and captain in 1913, and was considered to be one of the ablest officers in the Brazilian Navy. He was sent by the Brazilian Government to study electrical engineering in Belgium and America in 1905–1906, and in 1909 he was appointed Electrical Inspector of the Brazilian "Dreadnoughts" then building at Newcastle-on-Tyne and Barrow. He died of influenza at Rio de Janeiro on the 24th October, 1918, after having been in poor health for over two years. He was elected a Member of the Institution in 1913.

WILLIAM PERREN MAYCOCK died on the 29th June, 1918, at the comparatively early age of 53, and his death has left a gap in the ranks of electrical engineers which it will be difficult to fill. As a writer and teacher he made for himself a notable position, addressing himself mainly to the very large class of ambitious and industrious youths who are fighting their way upwards from very modest beginnings to positions of responsibility and prominence. As he had himself started life as an ordinary apprentice in the works of Messrs. Fuller & Son, telegraph and electric light engineers, at Bow, where he remained seven years, he had a clear understanding of the difficulties which hamper the efforts of a boy who has not had a proper grounding in scientific principles and mathematics, and who has to acquire technical knowledge from books, with little or no aid from an instructor. To such a one the ordinary textbook affords little help. Shut out from lectures and laboratory experience, he finds the descriptive matter inadequate and often unintelligible, while the mathematics is a stumbling-block rather than a help. He has never acquired the faculty of converting a formula into a mental image of complex and antagonistic forces, and derives no insight from it. What he craves for are diagrams and word pictures that cover the whole ground and call for little or no previous knowledge. In this kind of writing Mr. Maycock was pre-eminent. He had the faculty of seizing upon the main principles of a problem and putting it in the clearest light. He did not, however, confine himself to this. Every detail was dealt with in the most painstaking manner, always keeping in mind the deficiencies and shortcomings of the reader, and thinking no trouble too great if it ensured his understanding the subject. At the same time Mr. Maycock was never prolix. He had a happy knack of hitting upon the right word, and of finding brilliant illustrations and analogies to enforce his meaning. His own education had been liberal, first at the Reigate Grammar School, and later at Croydon at the Whitgift Grammar School, an ancient foundation which has turned out many notable scholars; Mr. Maycock afterwards taught electricity and magnetism for five years at the school. During his apprenticeship he attended the evening classes at the Finsbury Technical College under Professors Ayrton and Silvanus Thompson. His education did not, however, end with his college days. In the nineties electrical engineering was advancing rapidly, and Mr. Maycock kept himself abreast of every movement. He was obliged to be thorough, for it was impossible to write with the clarity to which he attained without having a complete mastery of the subject. Further, his knowledge was not merely academic, for he had had plenty of practical experience. From 1903 to 1908 he was with the British Westinghouse Electric and Manufacturing Company, Ltd., and since 1911 he had been associated with Messrs. A. P. Lundberg & Sons, for whom he prepared a series of handbooks. He was also for a short time connected with the Acme Electrical Works. His writing and teaching were largely done in his spare time, his teaching including classes in the South-Western, the Borough, and Croydon Polytechnics and work for the International Correspondence College, in each of which he was highly successful in interesting and guiding his pupils. His books have had a wide circulation and include the following: "Electric Lighting and Power Distribution"; "A First Book of Electricity and Magnetism"; "Alternating Current Work"; "Electric Light Fitting, Switches and Lamps"; "Electric Wiring Tables"; "Electric Wiring Diagrams"; "Electric Circuit Theory and Calculations"; "Continuous Current Motor and Control Systems," and a small book on electric motors. Besides these he contributed many papers to the Press. Mr. Maycock was a man of very genial disposition, with a keen sense of humour, a characteristic that was very evident in his contributions to the technical Press, and which he often employed with good effect in his textbooks to stimulate the interest of his readers. In 1905 he married Miss Florence Marion Hart, of Croydon, who with their two boys, aged respectively eleven and eight years, survives him. He was elected an Associate of the Institution in 1886 and a Member in 1891. B. A. R.

KOTARO MORISHIMA, member of the fifth class of the Imperial Japanese Order of the Sacred Treasure, died on the 25th February, 1917, at his residence near Kobe, Japan, after a long illness. He was born in August 1860 at Kokura and, after taking the electrical engineering course, graduated at the Imperial Japanese College of Engineering in May 1882. He at once obtained an appointment as an engineer in the Imperial Japanese Telegraph and Telephone Department, and remained in the Department until May 1903, when he resigned his position as Imperial Telegraph and Telephone Engineer. He then started business as a consulting engineer, and continued in the same work

until his death. He was elected a Foreign Member of the Institution in 1888 and a Member in 1911.

I. N.

HARRY RICHMOND MOTT was born in 1875 and died on the 13th February, 1919. After obtaining the Certificate of the City and Guilds Central Technical College he entered the service of the Metropolitan Electric Supply Company in January 1898 as an assistant to Mr. C. H. W. Gerhardi, the Chief of the Testing Department. He remained there until 1903, when he left to join the staff of the Electrical Inspector to the City of London Corporation as chief assistant to Mr. Voysey, and on the resignation of the latter he was appointed Electrical Engineer to the Corporation in January 1911. He had considerable natural aptitude in the use of tools and mechanical appliances, and was a capable mechanician, making some excellent models illustrating improvements in railway signalling systems. His work for the City Corporation included the establishment of the electrical ambulances, and their success owes much to his energy and technical knowledge. He also carried out the wiring of Gresham College, and the re-wiring of the Mansion House and other Corporation buildings. He was very popular with his colleagues, and his early death is much regretted by all who knew him. He joined the Institution as an Associate in 1898, was transferred to Associate Member in 1902, and Member in 1910.

F. B.

WILLIAM LLEWELLYN PREECE was the eldest son of the late Sir William Preece. He was born at Southampton in 1866, and passed away on the 10th November, 1918. He was not of a robust constitution, and had been in indifferent health for some years prior to his death. At the outbreak of the war he was eager to render what help he could, but he had perforce to content himself with performing the everyday duties necessary in the carrying on of the work of his firm. With the development of the naval electrical methods for the detection of the presence of submarines his opportunity came, and he was prompt to take it. Early in 1917 he was given an appointment at the Admiralty with the rank of Lieutenant in the R.N.V.R. The work was arduous and exacting in the extreme, involving unceasing application and effort, and it was soon obvious that the strain of it was having a serious effect upon his health. He kept on, however, until within a fortnight of his death, when under pressing medical advice he was compelled to relinquish his commission. At this time influenza was raging at its height, and he fell an easy victim to it. Pneumonia supervened, and the end came suddenly. In the great roll of illustrious names of those who have laid down their lives on the altar of duty in their country's cause, none deserves a more honourable place than that of Llewellyn Preece. His activities as an engineer are better known in the Colonies than in the Homeland. After completing his studies at the Electrical College, Hanover Square, in 1886, he joined the staff of the Midland Railway under that distinguished Railway Telegraph Engineer, the late W. E. Langdon, and in 1892 he was appointed Chief Assistant Engineer. Of his association with Mr. Langdon he always spoke in the most affectionate terms, and there is little doubt the sterling qualities of the chief helped to build up and crystallize those fine characteristics of uprightness and conscientiousness in Mr. Preece's nature, which were so distinctive in him in his later career. During this period his engineering responsibilities covered a wide field both in the power and lighting and in the electrical signalling systems of this important railway, and this experience had a marked influence upon his outlook later when questions concerning the application of machine generated electricity to telegraph and telephone systems came before him. In 1898 he resigned from the service of the Midland Railway and became a partner with Sir William Preece, just then retired from the Post Office, Major Cardew, and his brother Mr. A. H. Preece, in the firm Preece and Cardew, consulting engineers. In this combination of interests his telegraph experience enabled him to undertake, in co-operation with his father, the consulting work in connection with telegraph, telephone, and wireless engineering matters which were referred to the firm by the various Colonial Administrations. With the subsequent retirement of Sir William from active participation in the work of the office, the full responsibility for this side of the firm's business fell to him. In 1909 Sir John Snell joined the firm, and later Mr. John H. Rider, and the designation of the firm became Preece, Cardew, Snell and Rider. While most of his work was of a nature which could be dealt with in written reports, he was called upon at different times to give advice upon engineering matters on the spot. In 1912 he undertook a special investigation for the Government of the Federated Malay States of the telegraph and telephone systems in that Colony. He also visited Trinidad and other Colonies to report on similar questions. In 1916 he visited the United States in order to bring himself into touch with the latest developments in telegraphy and telephony in that country. In 1914 he entirely revised the well-known textbook on "Telegraphy" originally written by Sir William Preece and Sir James Sivewright. In 1915 he read a paper before the Institution upon "Telephone Troubles in the Tropics." In all these undertakings, as in his consulting work generally, he devoted himself unsparingly to the interests of the Colonial Administrations which he served. He was blessed with a keen perceptive faculty which enabled him quickly to grasp the essential points in a case, and he possessed a fund of knowledge of technical details which was almost inexhaustible. He never courted publicity in his work. Nature had blended in him in a remarkable degree the qualities of unfailing courtesy, delicate tactfulness, and obvious sincerity in all matters, and it is not too much to say that the many sterling virtues of his fine character earned for him not only the esteem, but also the affection, of countless officers of all grades of the Colonial services with whom he came in contact. In 1912 he gave evidence for the Post Office before the Parliamentary Committee upon the Marconi contracts in connection with the "Imperial" Wireless scheme, and for some time before he joined the Admiralty he was engaged in preparing a biography of Sir William Preece. He

was elected an Associate of the Institution in 1887 and a Member in 1907, and at the time of his death was a Member of the Council. He was also a Member of the Institution of Civil Engineers. He was a member of a number of other scientific institutions, was greatly interested in Church matters, and wrote many papers on religious subjects. Up to the time of his death he acted as Secretary of a branch of the Churchmen's Union. His religion was of a nature which withstood the wear and tear of everyday application. He was broad-minded and big-hearted, and at any time in his life it fittingly could have been said of him : " He hath a tear for pity and a hand open as day for melting charity." Latterly, his views on the hereafter coincided with those of other notable scientists of to-day, and to him his earthly end was but the passing over to a higher sphere of life. So may it be.

R. W. W.

ALPHONSE C. REYROLLE, who was the founder and Managing Director of Messrs. A. Reyrolle & Co., Ltd., of Hebburn-upon-Tyne, died at Newcastle on the 27th February, 1919. Although for 12 months he had known that his health was in a serious condition and that he had but little chance of recovery, he chose rather than rest, to devote all his waning strength to his life's work to the very end. He was a born mechanic, thorough in everything he undertook to do, always scrupulously careful in regard to details of manufacture, and with an unmistakable dislike for anything of a shoddy nature. Notwithstanding the extent of the work, it was his practice to inspect every new pattern made, and to the last he maintained a keen interest in the guidance and welfare of his employees, paying particular attention to the apprentices, for whom he organized a school for practical instruction. His individual ambition was always rather to foster good handicraft, of which he was a past master, than to establish a large works which he saw might grow beyond his sphere of personal control in detail He chose to live a comparatively quiet home life, but he had the personal characteristic of being genuinely attached to his old " friends," among whom few were so often in his thoughts as " my boys," as he called those who were engaged in his workshops. He was born in Juillac, Corrèze, France, in 1864, and his memory was very fresh in details of his experiences during the siege of 1870, when (as he had the misfortune to lose his mother) his father, a soldier then, took him with him to the trenches and on foraging expeditions on the outskirts of Paris. He came to London at the age of 19 as an improver to Messrs. Légé and Co., scientific instrument makers in Turk's Head-yard, Farringdon-street, where he developed his talent for accuracy and excellence of workmanship. In 1886 he started for himself in a small workshop at Charlotte-street, Fitzroy-square, and was soon sought after on account of his ability to develop new apparatus to the requirements of his clients, most of whom were pioneers in the electrical industry, and in this way he became associated with the early stages of many now well-known types of switchgear and electrical accessories. In 1897 he moved to Pancras-street, Tottenham Court-road. His personal energy and charm of manner to his friends will ever be affectionately remembered by those whose troubles he shared in the early days of many of the notorious stations, in London including Rathbone-place, Sardinia-street, Manchester-square. In 1901 he turned his private business into a limited company and opened the more extensive works at Hebburn, where some of the early lines developed in London were produced in bulk, and new lines were prepared to meet the conditions which grew with the progress of the large power companies on the North-East Coast. It may be truly said that his heart was in his work. He worked with persistent effort despite great stress occasioned by the war, increased by a love for France and a strong sense of duty for England, his country by adoption. His life work—well done—will be recognized as a contribution in no small measure to the conversion of electrical apparatus from the old " string and resin " to the " good job " state. He was elected a Member of the Institution in 1911.

H. W. C.

MARK RUDDLE was a native of Dublin, and served his engineering apprenticeship under the late Mr. G. Porte. Later he became engineer and manager of a large chemical works in Portsmouth, afterwards joining the Bell Telephone Company, which in 1880 amalgamated with the Edison Company of New York. The New York directors of the Edison Syndicate appointed him one of their engineers when they started business in London, and the first system of underground cables was laid down under his direction. He also acted as engineer to the Syndicate in Manchester, returning after some years to the Metropolitan Electric Lighting Company. Dublin, however, claimed him again in 1891, when he began his work with the Dublin electricity undertaking, and he represented the Corporation interests when the first generating station was erected in Fleet-street, Mr. E. Manville being the Consulting Engineer, and the Electrical Engineering Company of Ireland in conjunction with Messrs. Hammond and Company of London being the contractors. On the completion of the contract Mr. Ruddle was appointed Engineer to the undertaking. By 1891 the load on the Fleet-street station had increased to such a degree that the question of extensive addition to the station or the building of a new station in another district had to be considered, and it was decided to erect a new station on the Pigeon House site, some three miles from the centre of Dublin, on the river wall. Mr. Robert Hammond was appointed Consulting Engineer and Mr. Mark Ruddle supervised the whole work on behalf of the Corporation, this involved a change from the old single-phase 2,000-volt/100-volt system to the, then, new one of three-phase supply at 5,000 volts supplying lighting at 200 volts and power at 346 volts by means of static transform substations and 4-core distributors. The station as then erected was equipped for 3,000 kw., but additions were made from time to time and the capacity at the time of Mr. Ruddle's resignation amounted to 12,000 kw., all the additional plant being installed under Mr. Ruddle's direct supervision. Dublin can claim the distinction of being the first city in the kingdom to adopt the three-phase system

of generation with 4-wire distribution. In 1892, when the building of the new station at the Pigeon House was completed, Mr. Ruddle's official title was altered to that of City Electrical Engineer and this position he held at the time of his resignation early in 1919. He was elected an Associate of the Institution in 1892, an Associate Member in 1899 and a Member in 1902, and he served for a number of years on the Committee of the Dublin Local Section, being chairman of the Section in 1904–5. Mr. Ruddle also served for two years as President of the Institute of Civil Engineers of Ireland. G. A.

DAVID ALFRED STARR died on the 23rd June, 1919, at Bridge of Weir, near Glasgow, in his sixty-first year. He was born in Halifax, Nova Scotia, and educated at Mount Allison College, New Brunswick. After serving his apprenticeship in Halifax, he joined the Canadian Pacific Railway, Civil Engineers' Department, and was engaged for several years on the construction of that Company's main lines in Western Canada. Subsequently he crossed to the United States and joined the staff of the Thomson-Houston Company at their works in Lynn, Mass., returning in 1887 to Canada as General Sales Manager to the Royal Electric Company of Montreal. After seven years with the Royal Electric Company, he turned his attention to civil and electrical construction work, being contractor and engineer on the construction of, among others, the Hull and Alymer Railway and the Cornwall Street Railway. In 1900 he entered the service of the Westinghouse Electric & Manufacturing Company, and came to this country in 1901 to join the staff of the British Westinghouse Company at their Trafford Park Works, Manchester. In 1903 he was appointed General Manager of the Clyde Valley Electrical Power Company. At this date the majority of the power companies, as known to-day, had just been granted their Parliamentary powers. Under his immediate supervision the Company's power stations at Motherwell, Yoker, and Clyde's Mill were built, and the extra-high-tension distribution system installed. The Company's plant, which was largely extended during the war to meet the nation's demands, has now a capacity of 75,000 kilowatts. He was endowed with tremendous energy, and he spent this almost prodigally in his all-absorbing desire to ensure the Clyde Valley Company's growth and prosperity from the foundations which he had laid. He had the gift of leadership, possessing, as he did, a unique charm of manner, and his many friends cherish the memory of a big-hearted man. He was elected a Member of the Institution in 1909, and was Chairman of the Scottish Centre for the session 1915–16. A. P.

CHARLES HENRY STEARN was born in Jamaica in 1844. On leaving school he became a bank clerk, but devoted his spare time to physics and research. In 1877 he became associated with the late Sir Joseph Swan and endeavoured to produce a satisfactory glow lamp from carbon filaments prepared by Sir Joseph. Succeeding in doing so, a company was then formed in 1880 for the manufacture and development of the lamp, with Mr. Stearn as technical manager. In 1882 he was appointed managing director of the Swan United Electric Light Company. On the fusion of this Company with the Edison Electric Light Company he became associated with the Zurich Incandescence Lamp Company. When the Swan patents expired he started to manufacture electric lamps at Kew Gardens, the business of the Zurich Company being taken over in 1907 when the Stearn Electric Lamp Company was formed with Mr. Stearn as managing director. He took an active part in the management up to a short time of his death, which occurred after a short illness on the 14th February, 1919. Among his inventions was the process of making artificial silk from viscose. He was elected a Member of the Institution in 1884.

CAPTAIN GUY STAFFORD THORNE died of wounds as a prisoner of war after having been shot down at Arras on the 18th March, 1917. He was born at Wolverhampton in 1882, and, after having received his early education at the Grammar School of that town, entered the works of Messrs. Bellis and Morcom as an apprentice. Whilst serving his apprenticeship he attended evening classes at the Birmingham Technical School. On the completion of his indentures in 1904, he became chief assistant tester and subsequently out-working inspector and tester with Messrs. Bellis and Morcom. In May 1906 he was appointed chief assistant electrical engineer to the China Light and Power Company, becoming a few months later engineer-in-charge at the Canton Station. In July 1909 he was appointed Manager of the Chinese Government Power Company at Canton, a position which he retained until the outbreak of hostilities. He then returned to England, and, after having been appointed to a commission in the Royal Flying Corps, went to France in May 1916, being subsequently mentioned in despatches. He was elected an Associate Member of the Institution in 1912, and became a Member in 1914.

JOSEPH PATRICK TIERNEY died on 5th March, 1919, at the age of 38. He joined the electrical staff of the Dublin United Tramways Company in the year 1899 shortly after the electrification of the Dublin tramway system, and remained for 13 years in the service of the Company. During this period he invented and developed the type of electric point-shifter which is still used extensively in the Dublin district. On leaving the Tramway Company he became a consulting engineer and acquired a considerable practice throughout Ireland, holding the position of consulting engineer to several urban district councils. He was for some time engineer to the Dublin and Blessington Steam Tramway and was responsible for the introduction of petrol-electric cars on this line, having designed special cars for combined trolley and self-propelled operation. He was actively interested in a number of industrial undertakings, being engineer and manager of the De Selsby Quarries and engineer to the Skeagh Barytes Company. He lectured on electrical engineering at the City of Dublin Technical Schools from the year 1902 up to the time of his death. He was elected a Student of the Institution in 1901 and became a Member

in 1913. He served on the Dublin Committee for a number of years and occupied the position of Chairman of the Irish Centre at the time of his death. He read several papers before the Dublin Local Section, and his Address as Chairman in October 1918 has been published in the *Journal* (see page 27). W. T.

ERNEST OCTAVIUS WALKER, who died on the 12th February, 1919, was a son of Mr. G. J. Walker, and a grandson of Bishop Corrie of Madras. He was born at Teignmouth in 1850, and educated at private schools and at the Regent's Park College. In 1870 he went to the Hartley Institute, Southampton, and he also became a pupil of the late Sir William Preece and was trained for the Indian Telegraph Department, which he joined in 1871. He remained in India until 1892, and during his service in the Indian Telegraph Department was in charge of the telegraphs of the Lushai Expedition, 1889 to 1890. He was mentioned in despatches and awarded the C.I.E. He retired from India and subsequently, in 1895, became Superintendent of Telegraphs under the Ceylon Government, where he remained until 1899 when he joined the staff of Messrs. Preece & Cardew in Westminster. He was with them until 1912, in charge of much of their telegraph and telephone work for the various Colonial Governments. At the outbreak of war he placed his services at the disposal of the authorities, and he was employed upon censorship work for some time in London, also in Ireland. He contributed in 1883 a paper to the Institution on "Earth Currents in India" and on a "Magnetic Storm in India," and in 1888 he was awarded a Fahie premium for a further communication upon "Earth Currents in India" in that year. He also assisted with *Science Abstracts* and wrote many reviews of books on technical subjects. He was a man of charming personality. Among his colleagues in India and during his work in Westminster he was greatly respected by all. He was always ready to help, and never failed to give a patient hearing and sound advice to anyone in a difficulty. He was interested in many subjects, and in a quiet unobtrusive way did a great deal for the improvement of telegraphs and telephones in India and the Colonies. He was elected a Member of the Institution in 1878. A. H. P.

FREDERICK WARD was born on the 11th March, 1850, at Cambridge, in which town he was also educated. Soon after leaving school he took up telegraphy and obtained employment with railway and telegraph companies. In 1869 his connection with submarine telegraphy began when he was sent to Italy and Sicily, and he was afterwards stationed at Aden for some time. In 1871 he was selected, with a few others, to teach and develop telegraphy in Japan. Two decorations—the Order of the Rising Sun, and the Order of the Sacred Treasure—were conferred upon him for his services. He left the service of the Japanese Government in 1879 and accepted a position with the French Atlantic Cable Company, who appointed him to be Superintendent at Sydney, Cape Breton, Canada. When the Commercial Cable Company was organized in 1884 he transferred to that Company, and in the following year was stationed at Weston-super-Mare as superintendent, afterwards having charge also of the Bristol, Cardiff, and Swansea stations. He remained at Weston-super-Mare for 11 years, and was appointed Manager in England to the Commercial Cable Company at the beginning of 1896, which position he held until his death on the 23rd January, 1919. He was a great traveller and had a large experience, was an excellent linguist, speaking fluently several continental languages, and also spoke and wrote Japanese. In addition to his Japanese decorations he was awarded the Order of Christ by the Portuguese Government. He was elected an Associate of the Institution in 1886 and a Member in 1888.

HENRY WILDE, D.Sc., D.C.L., F.R.S., an Honorary Member of the Institution since 1898, died at his house, "The Hurst," Alderley Edge, Cheshire, on the 28th March, 1919. He was born in Manchester in 1833, and was left without parents when he was 16, having the charge of a younger brother, aged 12, and a sister. At an early age he was apprenticed to a mechanical engineer, and before his majority had attained a responsible position in the works. Keenly interested in the applications of electricity, he employed his leisure hours in making electrical machines, in experiments with electro-deposition, and with electric kites. At 23 years of age he commenced in business as a telegraph and lightning-conductor engineer. In the latter capacity he established a local reputation, and in a Lancashire town was known as "the leeghtning and thunder mon." He noticed that gas and water pipes caused fires by furnishing a path for electrical flow alternative to that of the lightning conductor, and he strongly urged that the pipes should be connected metallically with the rod, which is now the general practice. Several years were occupied in the design of an alphabetic telegraph, resulting in a number of patents relating to both the transmitter and the receiver. He succeeded in producing compact instruments and demonstrated their use at the International Exhibition held in London in 1862. The result of numerous experiments with magnetos led him to substitute permanent by electro-magnets. In 1863 he secured a patent for an electromagnetic generator which gave alternating currents from a shuttle-wound armature, the field being excited by the current from a battery or from a small direct-current magneto placed on the same foundation as the alternator and driven by the same power. Wilde used this machine for arc lighting and other purposes. Subsequently he provided this "electromagnetic machine" with a specially designed commutator so that direct currents could be produced. One of these generators with an armature 10 inches in diameter, when excited by a magneto having an armature $3\frac{1}{2}$ inches in diameter, would melt an iron rod $\frac{1}{4}$ inch in thickness and 14 inches in length. With the view of obtaining a generator which could be run at a relatively low speed and would not heat so much when under load, Wilde designed an entirely different type of machine having two circles of electromagnets between the poles of which rotated a multipolar armature. The field magnets were excited by a "minor" current obtained by rectifying the

alternating current from four of the armature bobbins. Normally the machine was an alternator, but it could be used to produce direct pulsating currents by a crown commutator. The output of the new machine was found much to exceed one of the earlier generators of the same weight. With two of the new alternators he made the important discovery in 1868 that it was possible to run them in parallel when synchronous. This was subsequently shown by John Hopkinson to be in accordance with mathematical theory. Many machines of both types were built by Wilde and Co. at the works in Manchester for electro-deposition and arc lighting. He developed both uses and took out a number of patents. Specially valuable was his patent of 1875 for making copper rollers for calico printing. He found that by giving a rotary motion to the electrolyte or the electrodes more powerful currents could be used and the rate of deposition be much increased. For electric lighting a number of arc lamps were designed. He used them for photographic and searchlight purposes. In 1912 he summarized this early use of his lighting plants in two papers, read before the Manchester Literary and Philosophical Society, having the titles "On Searchlights for the Mercantile Marine," and "Searchlights and the *Titanic* Disaster," in which he described the installation of his machines and lamps in 1876 on battleships.

His patents, especially those relating to electro-deposition, proved to be financially successful, and he was enabled to retire from business in 1884. During the following 35 years of his life he published many scientific papers. Their nature was, as a rule, very different from his early publications. From experimental work he turned to philosophical and, finally, theological considerations. This change was a gradual one.

In 1886 he determined the velocity with which air rushes into a vacuum, and he directed his attention to aviation. He described his early experiments "On Aerial Locomotion" in 1900, in which paper he said, "during a somewhat lengthy career as an experimentalist I have accumulated a considerable stock of negative knowledge"—a remark very much to the point when his many unsuccessful experiments for producing flight are examined; nevertheless, his confidence in the ultimate solution of the problem remained unshaken. Another subject which interested him was Terrestrial Magnetism, and he invented a "Magnetarium" which enabled him to reproduce the secular changes in the magnetic elements. He also published a number of papers on Atomic Weights and Astronomical subjects.

His record as an inventor establishes him as one of the pioneers of electrical engineering, but in Science he was not able to make progress with the times, owing to fixity of views and the want of preliminary training in modern methods. He was the recipient of many honours. In 1885 he was awarded a medal for his inventions at the International Inventions Exhibition held in London. In the following year he was elected a Fellow of the Royal Society. The honorary degree of D.Sc. was conferred upon him in 1900 by the Victoria University of Manchester, and three years later he received the D.C.L. degree of the University of Oxford. During 1894–6 he was President of the Manchester Literary and Philosophical Society.

Dr. Wilde was a liberal benefactor to public institutions. The full record of his gifts has not been declared. They include over £10,000 to the Manchester Literary and Philosophical Society; £5,500 to the Paris Academy of Sciences for an annual International Prize for discoveries in Science; £10,000 for the endowment of a Readership in Mental Philosophy, £3,000 to establish a Scholarship in Mental Philosophy, and £4,000 to endow a lectureship in Natural and Comparative Religion; all at the University of Oxford. The residue of his estate—about £10,000—also has been bequeathed to the same University. The Benevolent Fund of the Institution received from him a donation of £1,500 in 1900. For many years he had been a widower, and he had no children. W. W. H. G

ARNALDO PAOLO ZANI was born in December 1871, at Salo (Italy), and died at Vado Ligure (Italy), on the 23rd July, 1918. He received his scientific and mathematical training at the Pavia University, leaving with degrees in both these subjects; then entering the Milan Politecnico he specialized in electrical engineering, and graduated with honours from there in 1893. His engineering career started in the General Electric Company's designing office at Schenectady, U.S.A., where he remained for four years, the Company then sending him to Berlin as Chief Engineer to the Union E.G., and afterwards to the Thomson-Houston de la Mediteranée (Milan), who proposed to erect large electrical works in Italy. This scheme, however, did not mature, owing to the already powerful influence of the competing German interests. He then joined Messrs. Dick, Kerr & Company, who had recently started their new Preston works, remaining with them until 1913. He was one of the pioneers of the manufacture of large alternators in England. The *Engineer* of the 30th October, 1903, contains a description of what was at that time the largest alternator built in the works of Messrs. Dick, Kerr & Company; this machine was designed by him. In 1913, being anxious to get nearer to his native country, he joined the French Thomson-Houston Company of Paris as Chief Engineer of all their works. When Italy joined in the War in August, 1915, he decided to return to that country, taking up the position of General Manager of the Italian Westinghouse Company, at Vado Ligure, for the purpose of reorganizing these works which had been, until then, under the management of aliens. He devoted all his energies to this new task, fighting against difficulties of every kind, until his health was gradually affected by excessive overwork and worry, and he died after a few days' illness at Vado Ligure, at the moment when his life's dream of making a great purely Italian electrical factory, free from German influences, was practically realized. He was a clever mathematician, besides being a practical designer, and the electrical industry has prematurely lost one of its best men. He was elected a Member of the Institution in 1907. P. B.

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EXPLANATION OF ABBREVIATIONS.

(P) indicates a reference to the general title or subject of a paper or address.

(p) indicates a reference to a subject dealt with in a paper or address of which the title is not quoted.

(D) indicates a reference to a discussion upon a paper or address of which the general title or subject is quoted.

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